Fisheries and Oceans Canada / Pêches et Océans Canada

Science / Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/001

Maritimes Region

Musquash Estuary Marine Protected Area (MPA): Data Assessment

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September 2014

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Cooper, A., Abbott M., Allard, K., Chang, B., Courtenay, S., Doherty, P., Greenlaw, M., Ipsen, E., Koropatnick, T., Law, B., Losier, R., Martin, J., Methven, D., and Page, F. 2014. Musquash Estuary Marine Protected Area (MPA): Data Assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/001. v + 57 p.

TABLE OF CONTENTS

ABSTRACT

The Musquash Estuary is located 20 km southwest of Saint John, New Brunswick. On December 14, 2006, the lands and water in the Musquash Estuary up to mean low water were designated a Marine Protected Area (MPA) through regulations pursuant to Canada's *Ocean Act*. Fifteen indicators have been proposed in the framework to monitor the conservation objectives that have been established for managing the MPA and Administered Intertidal Area.

A range of protocols and strategies have also been proposed to monitor each of the identified indicators. Although management actions are currently being undertaken to regulate human activities in the protected area, an understanding of the baseline state of the ecosystem in the estuary is required in order to determine the success of Fisheries and Oceans Canada management actions. This document presents a summary of the current research and monitoring activities undertaken by individual researchers, stakeholder groups and interested government departments within the Musquash MPA and surrounding area. These results were used to assess whether the research and monitoring activities to date in the MPA have provided an adequate baseline upon which to base future monitoring activities and whether the indicators are likely to be effective in assessing ecosystem change. Results indicate that sampling activities to date have provided adequate baseline data on fish assemblages, benthic diversity, sediment characteristics, and physical oceanography for the Musquash Estuary. Current commercial and recreational fishing data is not at a scale that is useful for monitoring. Although the spatial and temporal extent of natural variation has yet to be determined for the proposed monitoring indicators, the results of the baseline data collection should be incorporated into a monitoring plan, as the foundation for future monitoring activity.

Zone de protection marine de l'estuaire Musquash (ZPM) : Évaluation des données

RÉSUMÉ

L'estuaire Musquash se situe à 20 km au sud-ouest de Saint John, au Nouveau-Brunswick. Le 14 décembre 2006, les terres et les eaux de l'estuaire Musquash jusqu'au niveau moyen des basses eaux ont été désignées zone de protection marine (ZPM) par le Règlement établi en vertu de la *Loi sur les océans* fédérale. On a proposé quinze indicateurs dans le cadre de la surveillance des objectifs de conservation établis pour gérer la ZPM et la zone intertidale administrée.

Une gamme de protocoles et de stratégies ont aussi été proposés pour surveiller chacun des indicateurs désignés. Bien que des mesures de gestion soient actuellement mises en œuvre pour réglementer l'activité humaine dans la zone protégée, une compréhension de l'état de référence de l'écosystème dans l'estuaire est nécessaire pour déterminer la réussite des mesures de gestion de Pêches et Océans Canada. Ce document présente un résumé des activités de recherche et de surveillance actuelles entreprises par les chercheurs individuels, les groupes d'intervenants et les ministères intéressés à l'intérieur de la zone de protection marine Musquash et de la zone environnante. Les résultats seront utilisés pour évaluer si les activités de recherche et de surveillance jusqu'ici dans la ZPM ont fourni une base de référence adéquate sur laquelle fonder les activités de surveillance futures et si les indicateurs sont susceptibles d'être efficaces pour évaluer les changements écosystémiques. Les résultats indiquent que les activités d'échantillonnage à ce jour ont fourni une base de référence adéquate sur les assemblages de poissons, la diversité benthique, les caractéristiques des sédiments et l'océanographie physique de l'estuaire Musquash. Les données actuelles sur la pêche commerciale et récréative ne sont pas à une échelle utile pour la surveillance. Même si la couverture spatiale et temporelle de la variation naturelle n'a pas encore été établie pour les indicateurs de surveillance proposés, les résultats de la collecte de données de référence doivent être incorporés dans un plan de surveillance à titre de fondement de l'activité de surveillance future.

INTRODUCTION

MUSQUASH ESTUARY

The Musquash Estuary is located 20 km southwest of Saint John, New Brunswick (Figure 1). Its large size, expansive salt marshes, and relatively undisturbed natural condition make it unique among estuaries in the Bay of Fundy. The estuary is the largest ecologically-intact estuary in the Bay of Fundy and supports a rich and productive habitat for a diverse number of invertebrates, fish, wildlife, and marine plants. For a comprehensive ecological overview of the Musquash Estuary refer to Singh et al. (2000).

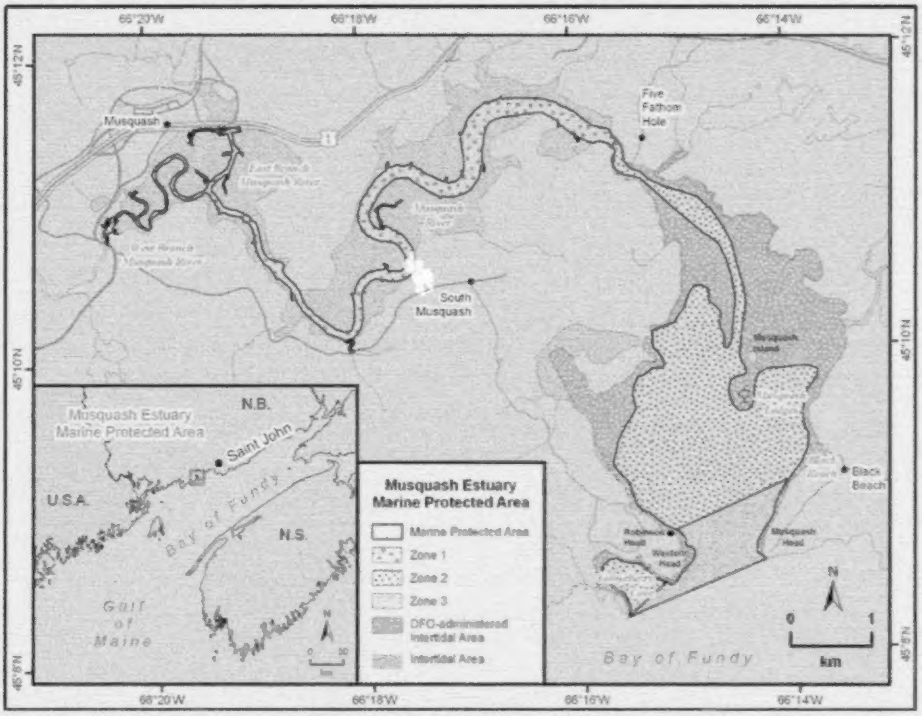


Figure 1. Map of Musquash Estuary Marine Protected Area (MPA) and Administered Intertidal Area (AIA) that are managed by Fisheries and Oceans Canada (DFO).

The Musquash Estuary is comprised of a large embayment with a relatively narrow and deep entrance between the two rocky headlands of Western Head and Musquash Head (Hunter and Associates 1982; Singh et al. 2000). The Musquash River flows into the shallow Musquash Harbour. The estuary drains the Musquash River and adjacent salt marshes. Musquash Estuary is a shallow, tidal estuarine ecosystem. It exhibits mid-channel water depths of 1-6 m at low tide and a tidal range of 6-8 m (Wildish 1977; Gratto 1986). Musquash Harbour is highly turbid (i.e., muddy) due to the resuspension of bottom sediment associated with strong tidal currents (Dowd et al., unpublished data[1]).

Suspended sediment in the estuary is discharged into the Bay of Fundy during the ebb tide and transported further upstream during the flood tide. Freshwater discharge into the estuary passes through a small, deactivated electric dam in the Musquash River and from several small creeks,

[1] Unpublished oceanographic data of Musquash Estuary recorded in September 1999 by M. Dowd, F. Page, R. Losier, M. Ringuette and P. McCurdy of DFO, Maritimes Region, St. Andrews, NB (1999).

and salinity in Musquash Harbour varies depending on the balance between freshwater inputs and seawater from the Bay of Fundy. Water in the estuary was observed to be vertically well mixed between the surface and bottom in the spring (Kristmanson 1974) and late summer (Dowd et al., unpublished data[1]) and, perhaps, throughout most of the year (Singh et. al. 2000).

A Marine Protected Area (MPA) is a coastal or marine area given special status to conserve and protect its natural habitat and marine life. On December 14, 2006, the lands and water in the Musquash Estuary up to mean low water were designated a MPA through regulations pursuant to Canada's *Ocean Act*. The *Oceans Act*, however, do not apply to the lands and waters between mean low and mean high water levels, and, as a result, the Musquash Estuary MPA Regulations do not apply to the intertidal area administered by Fisheries and Oceans Canada (DFO) . This area, referred to as the Administered Intertidal Area (AIA), was transferred from the province of New Brunswick to DFO and is managed, as part of the MPA, pursuant to the *Fisheries Act*, *Federal Real Property and Federal Immovables Act*, and other applicable legislation (e.g., *New Brunswick Trespass Act*, etc.) Throughout this document, reference to the MPA includes both the MPA and AIA.

The Musquash Estuary is divided into four distinct management zones that provide the foundation for managing human activities in the MPA. The level of conservation and protection in each management zone depends on the ecological sensitivity of the zone and the ability to accommodate human activities.

MONITORING FRAMEWORK

To ensure conservation and protection of the Musquash Estuary, DFO has developed a plan to manage human activities in the MPA entitled 'Musquash Estuary: A Management Plan for the Marine Protected Area and Administered Intertidal Area" (DFO 2008). An ecosystem-level management framework which identifies monitoring strategies to evaluate the state of the Musquash Estuary ecosystem as it pertains to stated conservation objectives was developed in 2007 (Singh and Buzeta 2007). Conservation objectives for the Musquash Estuary MPA are to ensure that there is no unacceptable reduction or human-caused modification in:

1. productivity, so that each component can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species;
2. biodiversity by maintaining the diversity of individual species, communities, and populations within different ecotypes; and
3. habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality.

Fifteen indicators (Appendix 1) have been proposed in the framework to monitor the conservation objectives that have been established for managing the MPA (DFO 2011). A range of protocols have also been proposed to monitor each of the identified indicators. Although management actions are currently being undertaken to regulate human activities in the protected area, an understanding of the baseline state of the ecosystem in the estuary is required in order to determine the success of DFO's management actions.

Baseline data establishes an ecological benchmark by which future MPA performance can be measured and assessed to determine whether there have been any initial changes resulting from MPA implementation. It also offers a determination of spatial and temporal variability, minimum sample size, and correlation with other environmental variables including perceived and managed threats. A lack of baseline data exists for many aspects of the Musquash Estuary ecosystem; thus, the proposed indicators are general guidelines, with the range of monitoring strategies being proposed as a first step to evaluating indicators. As baseline information improves, strategies, protocols and indicators may be refined, added or deleted from the

monitoring plan (Cooper et al. 2011). The combination of baseline data and linkages to management objectives should allow for the development of reference points and provide an ecosystem overview, as well as describe the effects of human activities on it (Kenchington 2010).

CURRENT STATE OF MONITORING

Research and monitoring activities pertaining to benthic biodiversity, physical oceanography, sedimentation rates and metal history, fish community assemblages, bird population surveys, and human threats have been and continue to be undertaken in the Musquash Estuary, although no systematic monitoring to evaluate against conservation objectives of the MPA has been completed to date. Many of the monitoring activities are undertaken by individual researchers, stakeholder groups, and interested government departments. A list of current monitoring activities, along with information on protocols, and analysis are below.

PHYSICAL ENVIRONMENT

Authors: F.H. Page, B.D. Chang, R.J. Losier

The MPA is an open system. Freshwater enters from the landward drainage system and exits through the MPA mouth, whereas saltwater enters and exits through the seaward boundary (Figure 2). The MPA ecosystem status is influenced by variations in the rates of these freshwater and saltwater flows and by what is carried by the flows. The variations are dominated by tidal processes and by aperiodic events such as heavy rainfalls and strong winds. Hence, developing an understanding of the temporal character of the fluxes, the associated spatial and temporal variations in the water circulation patterns within the MPA, and the combined influence of these on the status and dynamics of the MPA is useful and necessary background information for the MPA.

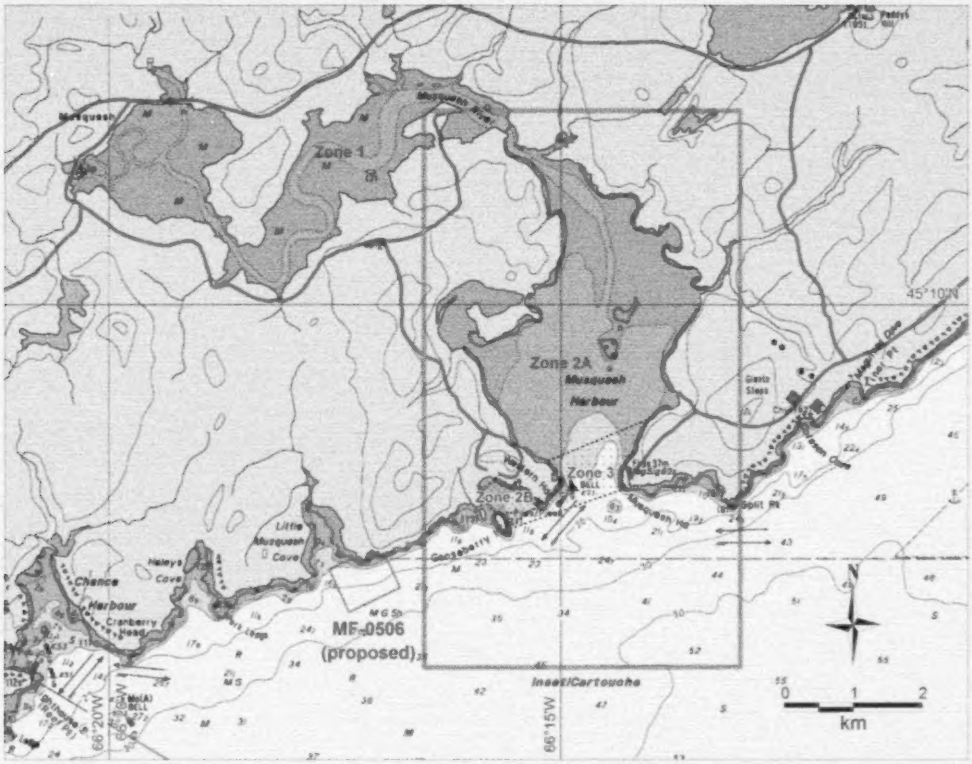


Figure 2. Map of Musquash Estuary MPA. The map also shows proposed finfish aquaculture lease MF-0506, which was not approved. Background map is a detail of Canadian Hydrographic Service chart 411601 (Maces Bay to Saint John).

Available Dataset

Monitoring activities and water exchange research in the MPA fall into four categories:

- continuous measurement of freshwater inflow into the MPA;
- occasional monitoring of temperature, salinity, turbidity, dissolved oxygen, chlorophyll, and water currents within the MPA and in the adjacent waters of the Bay of Fundy; and
- models of the tidal water circulation within the MPA and in the adjacent waters of the Bay of Fundy.

Data Collection

River Flow

River flow monitoring stations were established at two locations near the mouths of the East and West branches of the Musquash River (Figure 3). In addition, a monitoring station at the nearby Lepreau River has been operated by Environment Canada for the past 97 years (Figure 3). The objectives of the freshwater input monitoring are to examine the temporal behavior of the East Branch and West Branch discharges and to quantify the freshwater river inputs to the Musquash Estuary.

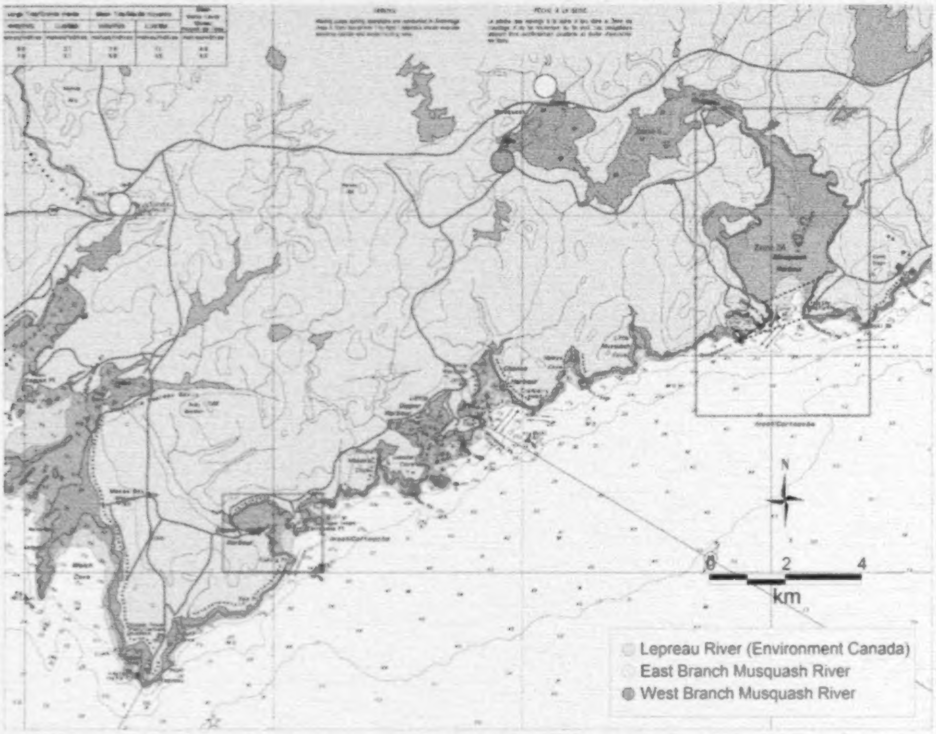


Figure 3. Map of Musquash River and Lepreau River flow monitoring station locations.

At each of the two monitoring locations, HOBO U20 Titanium Water Level Data Loggers were placed within submerged monitoring wells on 7 March 2012. The locations were selected based on ease of accessibility, water depth, channel geometry, and bottom composition.

River discharge in nearby portions of the river channels was measured at various points in time using a RiverRay Acoustic Doppler Current Profiler (ADCP), with Hemisphere GPS, and an Ocean Science High Speed River Boat (HSRB). In some cases, the discharge was measured using a SonTek Flowtracker and Wading Rod. In both cases, repeat measurements indicated that relative discharge measurements varied by <5%.

Environmental Monitoring

Environmental monitoring includes the collection of background/baseline data on physical factors (temperature, salinity, dissolved oxygen, turbidity) and biological factors (chlorophyll, phytoplankton, benthos).

Monitoring to date has included the taking of vertical depth profiles of water conductivity, temperature, salinity, dissolved oxygen, turbidity, and photosynthetic active radiation in 1999-2000 at a series of stations distributed along the axis of the MPA estuary and the deployment of internally recording YSI Sondes at several locations for periods of weeks in 2008 (Figure 4). In addition, temperature and salinity profiles, as well as geo-positioned photographs, were collected during the Musquash Annual Canoe Paddle organized by M. Abbott on 21 July 2012 (Figure 5).

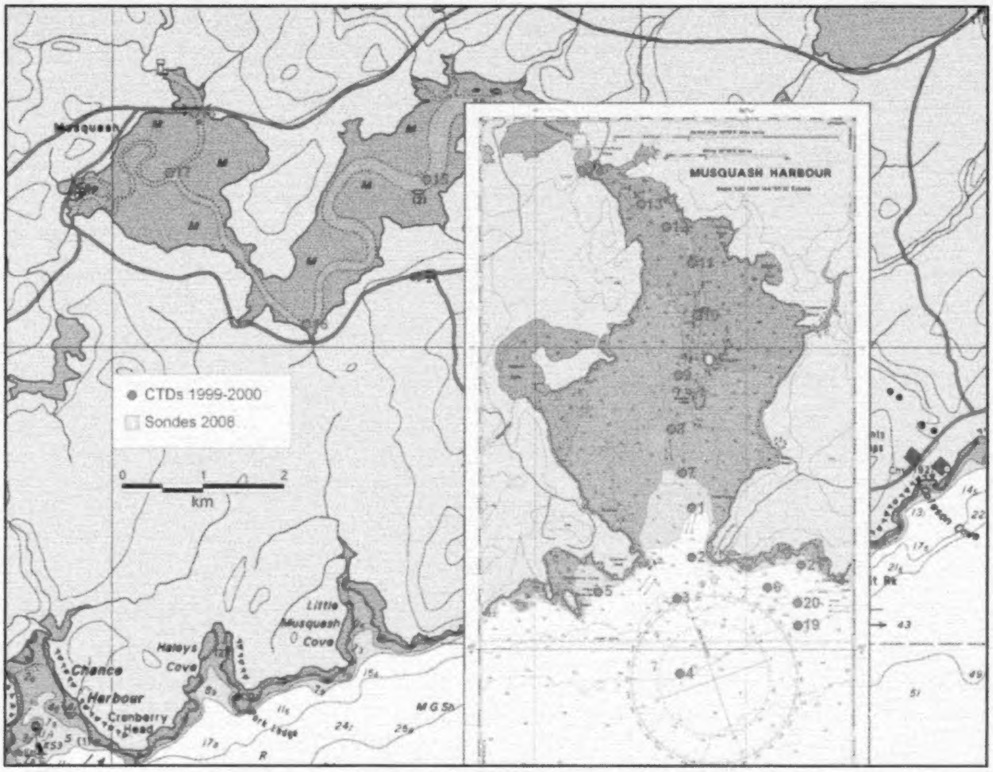


Figure 4. Map of Musquash estuary showing locations of conductivity, temperature, and depth (CTD) deployments in 1999-2000 (Singh et al. 2000) and YSI Sonde deployments in 2008.

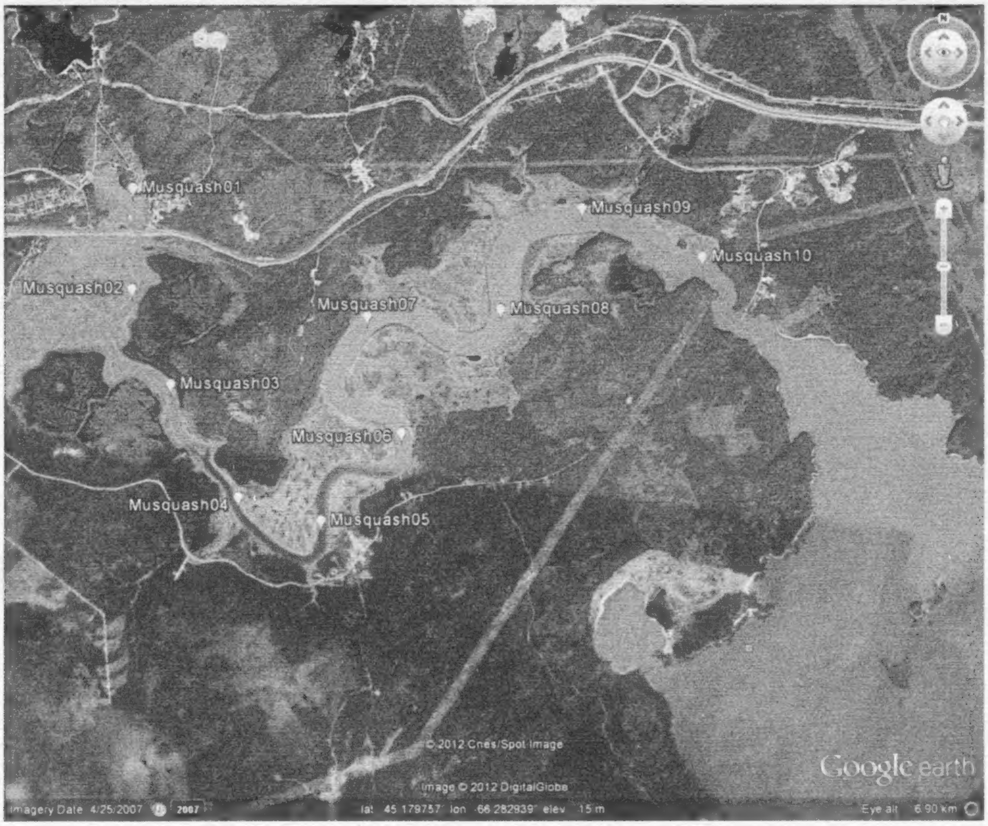


Figure 5. Locations of temperature and salinity depth profiles collected during the annual Musquash Paddle, 21 July 2012.

Water Currents

Current meter deployments to date include ADCPs mounted on the seafloor or just above the seafloor, and S4 current meters mounted at specific depths. The ADCPs measure currents throughout the water column, while the S4s measure currents only at the instrument depth. Current meters were deployed at various locations within and just outside the estuary in 2008 (Figure 6). These deployments were conducted to examine water circulation in relation to a proposed salmon farm at Little Musquash Cove, just west of the MPA (see Figure 2).

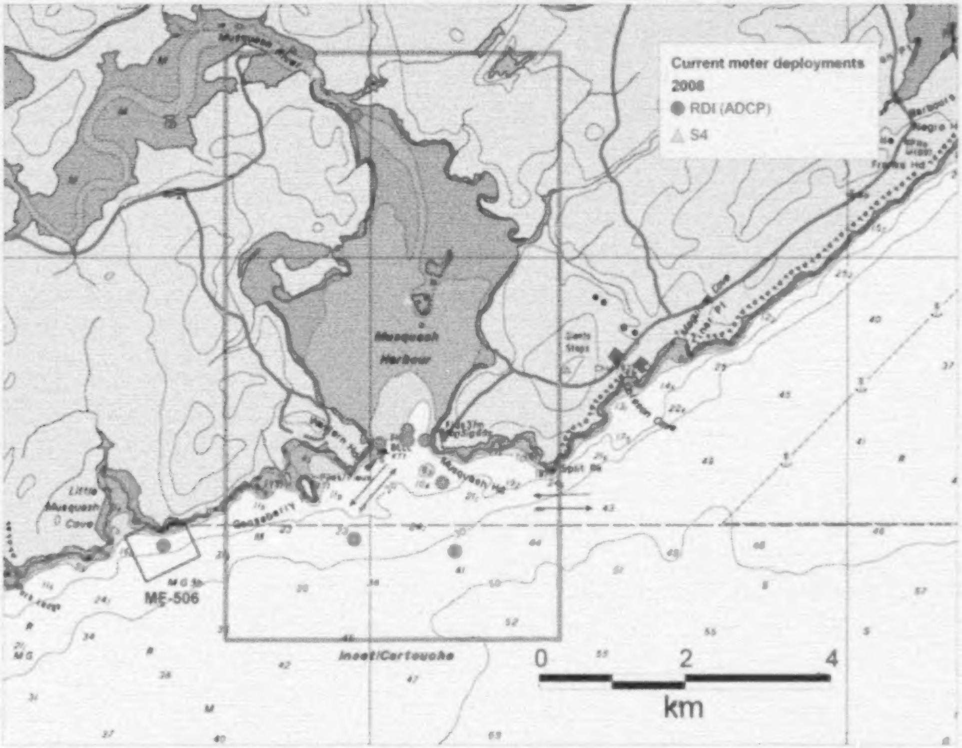


Figure 6. Locations of current meter deployments in the Musquash estuary area in 2008.

Water exchange was also investigated by the Ocean Mapping Group (OMG), University of New Brunswick, Fredericton, NB (Hughes Clarke et al. 2003). The OMG conducted an ADCP survey near the mouth of the MPA in September 2001. The survey was repeated several times over a tidal cycle to provide information on the variability of the current on time scales of a tidal cycle (12.4 hours).

Surface drifters were also deployed to track water currents in relation to the proposed salmon farm at Little Musquash Cove. These drifters followed the currents in the top 1 m of the water column. The GPS position of each drifter was recorded every 11-12 minutes and the position was also transmitted to the ARGOS satellite system.

Water Circulation Modelling

A three-dimensional finite volume model has been developed for the Bay of Fundy area, including the Musquash Estuary. The model is fully non-linear, including inter-tidal drying and 21 sigma (depth) levels, with a horizontal resolution of <50 m. The model is driven by multiple tidal constituents, winds, and density, and uses spherical polar coordinates. The coastline and depths were obtained from the Canadian Hydrographic Service (Dartmouth, NS). Work was conducted to refine the grid in the Musquash area. Some model runs were conducted and preliminary comparisons to observations were made.

Features of Existing Time Series

River Flow

Lepreau River discharge rates in the spring of 2012 (as measured by Environment Canada) showed peaks associated with heavy precipitation. Flows in the East Branch were correlated with Lepreau River flows in March and early April, but the former were impacted by human

intervention in mid-April, resulting in flows dropping to zero (Figure 7). The introduction of the human factor into flow control out of the Musquash Lake system means the Lepreau River discharge data cannot be relied upon to provide a good relative index of flow into the MPA.

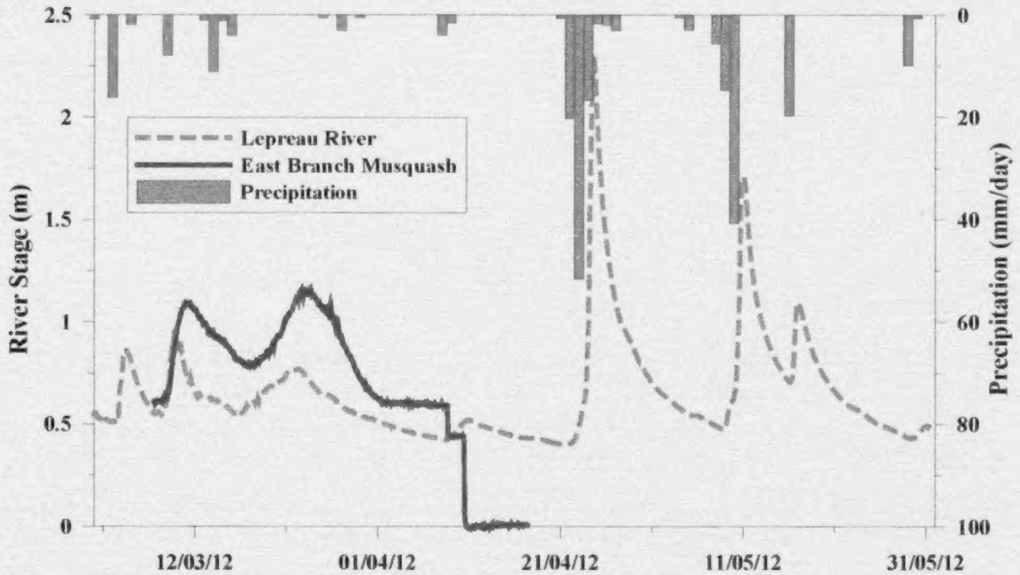


Figure 7. River stage (water level) and precipitation data for the Lepreau River and the Musquash River East Branch in March-May 2012.

Although some data has been collected to define the relationship between the river discharge rate (volume of water flowing through a river cross section per unit time) and the river stage (water level), more data is required, particularly at high flow rates, before a complete river discharge curve can be derived (Table 1).

Table 1. Relationships between discharge rate and river stage (water level) at the Musquash and Lepreau Rivers.

	Discharge (m^3/s)			Raw water level (m)			
Date	East Branch	West Branch	Lepreau	East Branch	West Branch	Lepreau	Discharge Instrument
23/09/2011	0.254	1.397	1.475	-	-	0.307	Sontek Flow Tracker
22/03/2012	9.552	-	14.030	1.053	-	0.756	RiverRay
17/04/2012	0.144	-	3.670	-	-	0.432	RiverRay
28/05/2012	0.557	-	3.960	-	-	0.445	RiverRay
01/06/2012	5.751	10.381	5.100	-	-	0.492	RiverRay

Note: Cells marked with a dash (-) indicate that data are not available.

Environmental Monitoring

Data from the 1999-2000 CTD deployments were previously reported (Singh et al. 2000). Sample data from the 2008 YSI Sonde deployments are shown in Figure 8. The time series are characterized by tidal variations and aperiodic event variations. This means monitoring of the MPA and interpretation of observations will need to account for these high frequency variations before long term change can be detected.

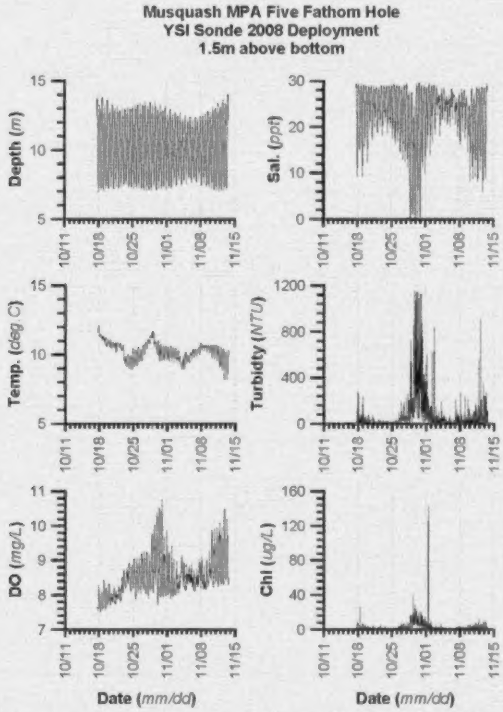


Figure 8a. Data from a YSI Sonde deployment at Five Fathom Hole in October-November 2008, 1.5 m above bottom.

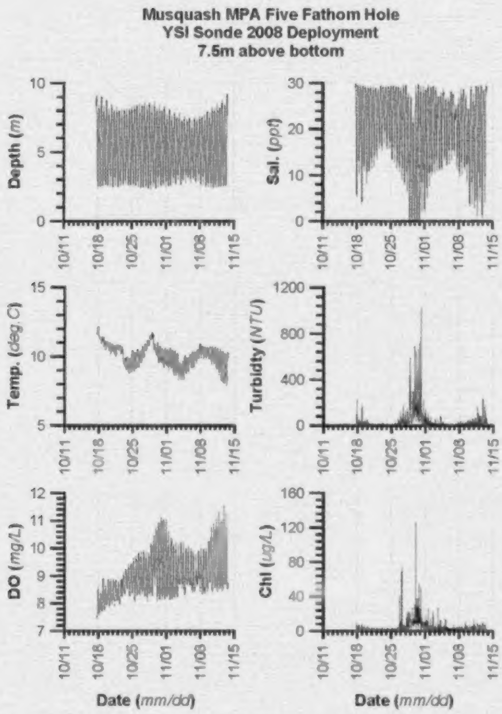
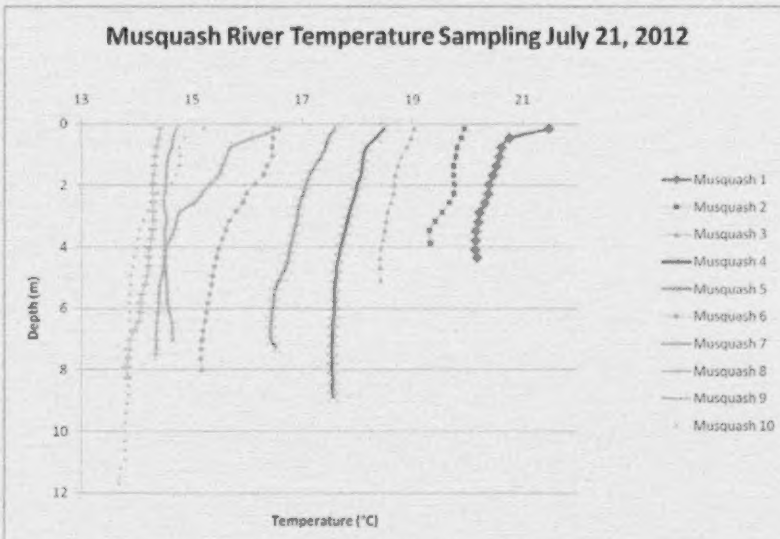


Figure 8b. Data from a YSI Sonde deployment at Five Fathom Hole in October-November 2008, 7.5 m above bottom.

Temperature and salinity profiles from the 2012 Musquash Paddle are shown in Figure 9. The profiles are consistent with those taken in 1999-2000 and reported on in Singh et al. (2000). They show the water column at the head of the estuary can be vertically stratified and is reasonably well mixed in the vertical throughout most of the reminder of the estuary. They also show that the water salinity increases by approximately 20 practical salinity units (psu) from very low salinity at the head of the estuary to full seawater salinity at the mouth of the estuary. The water temperature in July increases by about 6°C from a high at the head of the estuary and a low at the mouth.



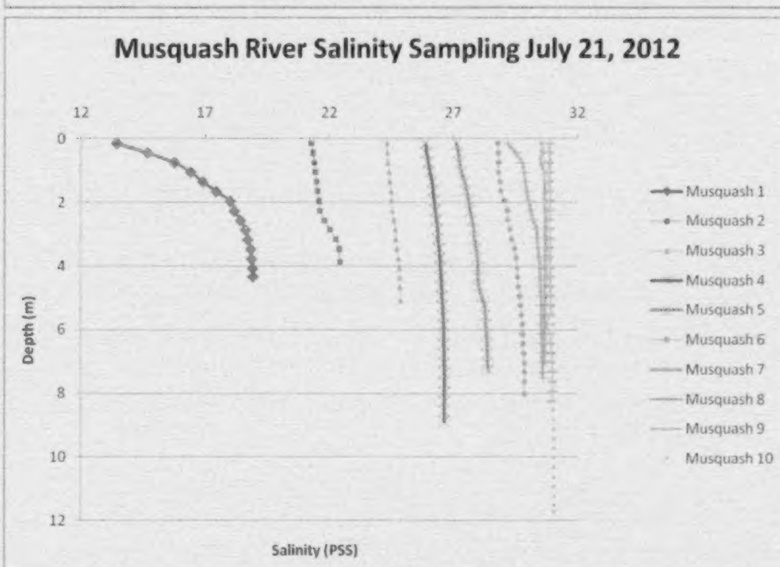


Figure 9. Temperature (top) and salinity (bottom) depth profiles collected during the annual Musquash Paddle, 21 July 2012. See Figure 4 for sampling locations.

Water Currents

On the west side of the mouth of Musquash Harbour, the net flow during the measurement period appears to be out of the MPA, while on the east side, the net flow is into the MPA (Figure 9). At Five Fathom Hole, there was a weak net flow into the MPA (Figure 10).

Notable characteristics of the M2 tidal circulation pattern based on the OMG survey are that the early ebbing flow out of the MPA is constrained to the west, whereas the late ebb switches to the east. The flood flow into the MPA is dominantly constrained to the east, and the flow about a kilometer offshore of the MPA mouth is rectilinear flow along an east-west axis (Figure 11).

Although only a few drifter experiments have been conducted, the recorded drift tracks of drifters released outside of the MPA are dominated by the east-west rectilinear tidal flow (Figure 12). The drifters released inside the MPA near Five Fathom Hole drifted along the western side of the MPA in a southerly direction and exited the MPA on the west side (Figure 12 from Page et al. 2009).

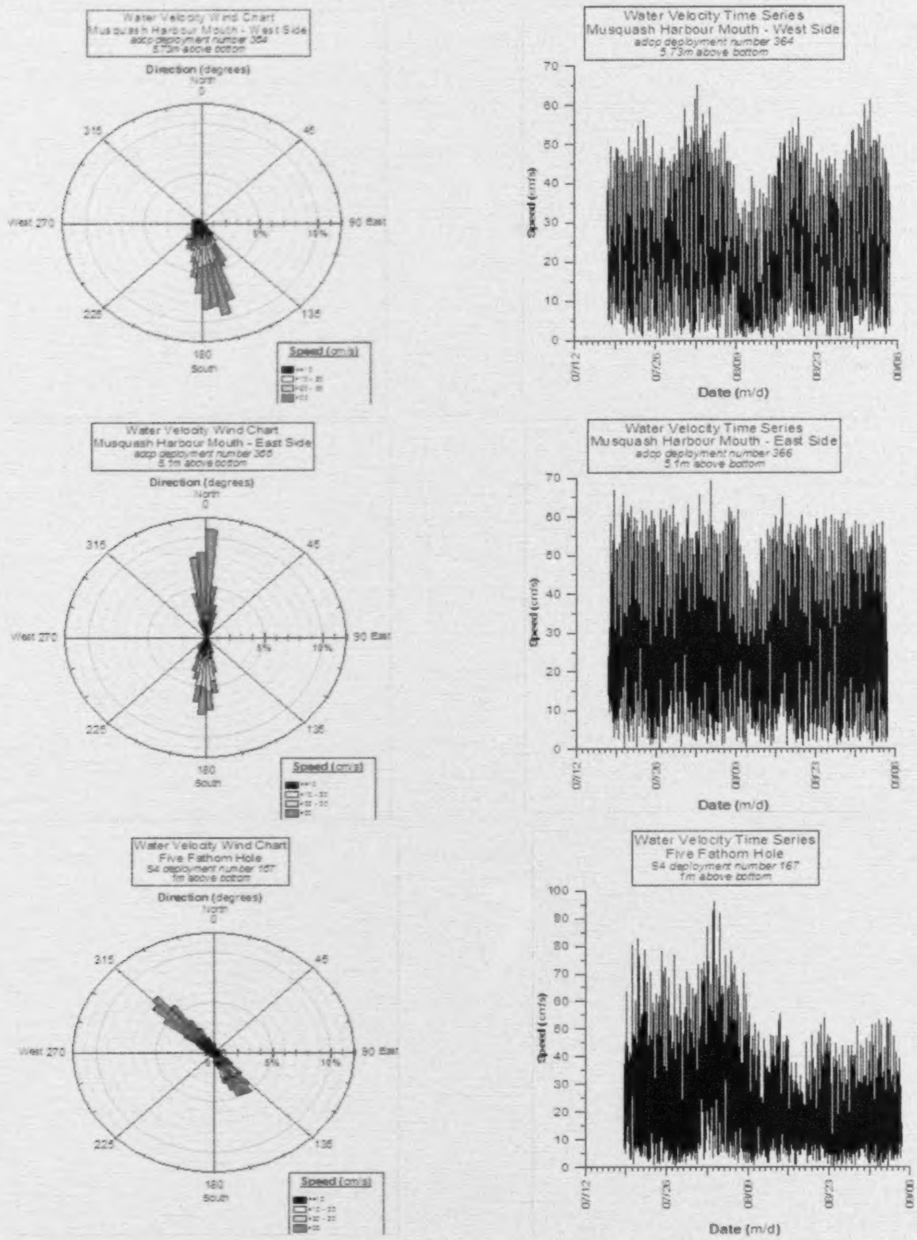


Figure 10. Current velocity data collected at the mouth of Musquash Harbour, west side (top), the mouth of Musquash Harbour, east side (middle), and at Five Fathom Hole (bottom) in July 2008.

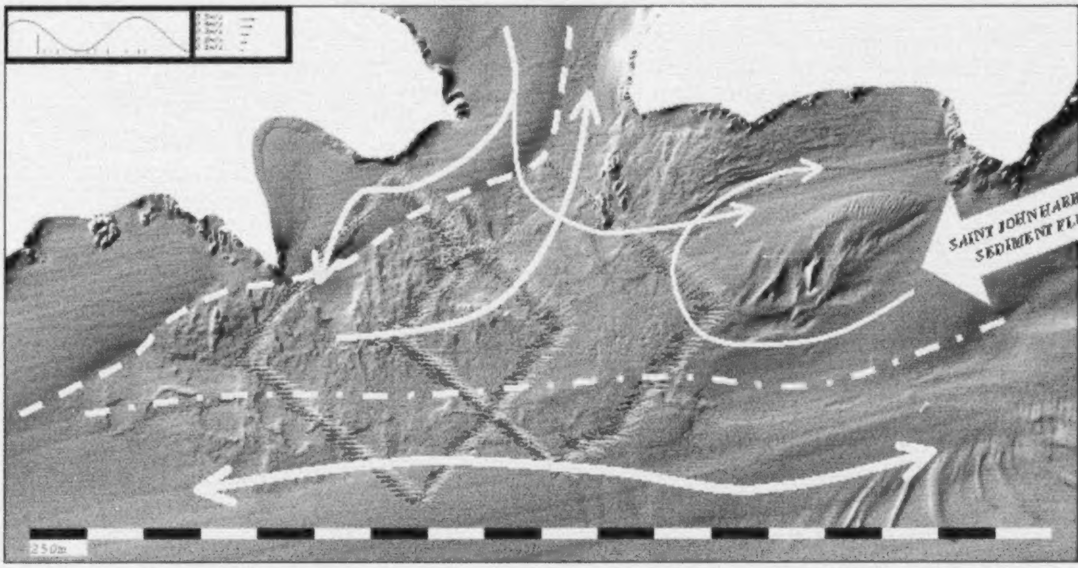


Figure 11. Summary of the ADCP survey conducted in September 2001 by the Ocean Mapping Group at the University of New Brunswick (Hughes Clarke et al. 2003). The diamond shapes represent the ADCP survey track.

Photographs

Photographs at specific locations have been taken during the annual MPA canoe paddle. The photographs record the very general condition of the MPA scene rather than specific details. On-going refinements and discussions will be needed to clarify the usefulness and proper protocols for photographs.

Water Circulation Modelling

The finite volume coastal ocean model (FVCOM) numerical grid has been refined for the Musquash Estuary area (Figure 13). Stable tidal circulation runs have been made (Figure 14), and preliminary comparisons of model output to current meter observations have been made. More comparisons and model refinements are needed.

Baseline Values and Reference Points

There are insufficient physical environmental data to adequately determine baseline values and reference points for:

- Freshwater input, since a discharge curve has not yet been established and less than one year of data has been collected. Due to the natural temporal variation in, and the human influence on, the freshwater inflows, freshwater inputs will need to be monitored indefinitely.
- Environmental variables (temperature, salinity, oxygen, turbidity, and chlorophyll), since these are highly variable on temporal scales of hours and weeks to months, several years of time series data will be needed to provide a solid background characterization. This will require secure mooring platforms (theft-proof).

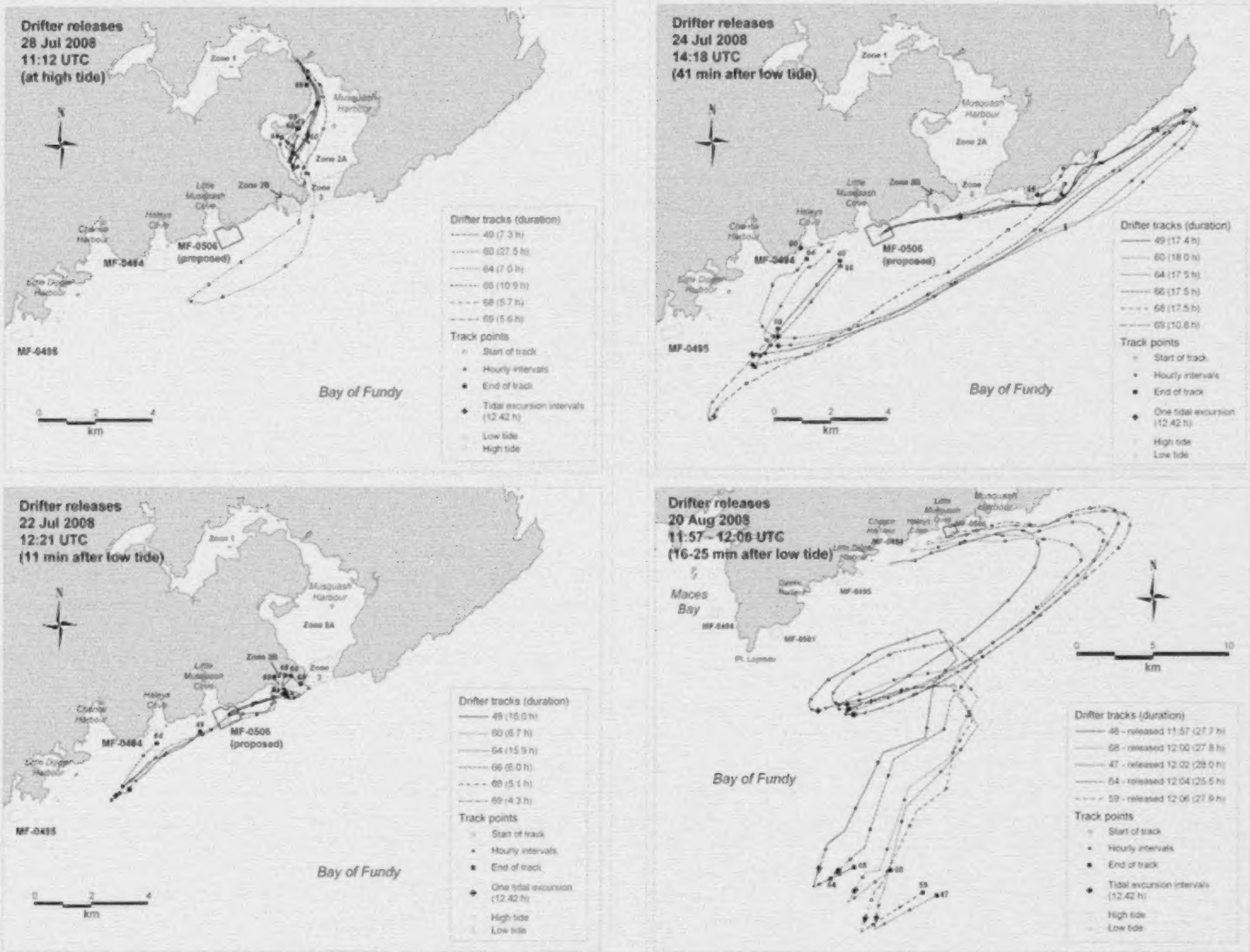


Figure 12. Sample drifter tracks from the Musquash area (from Page et al. 2009).

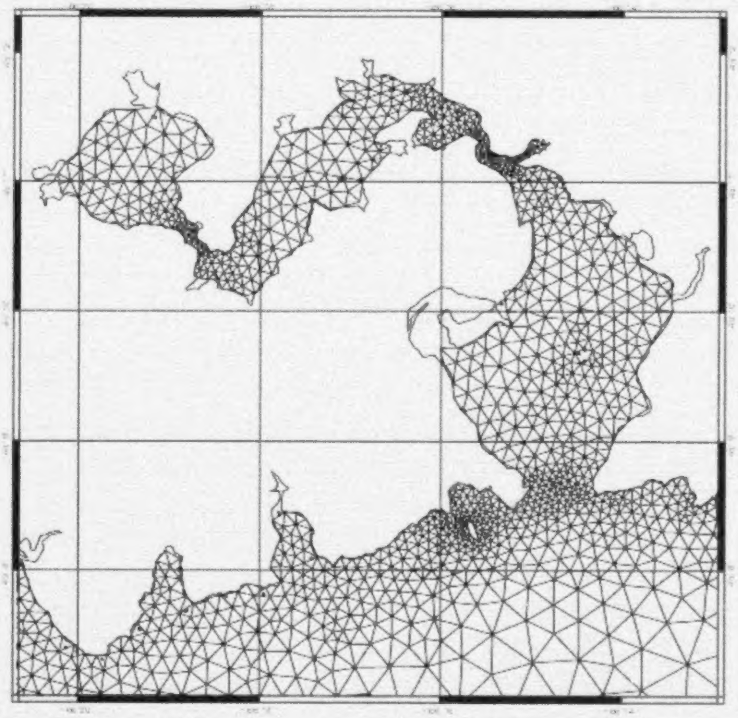


Figure 13. Model grid for the FVCOM circulation model in the Musquash area.

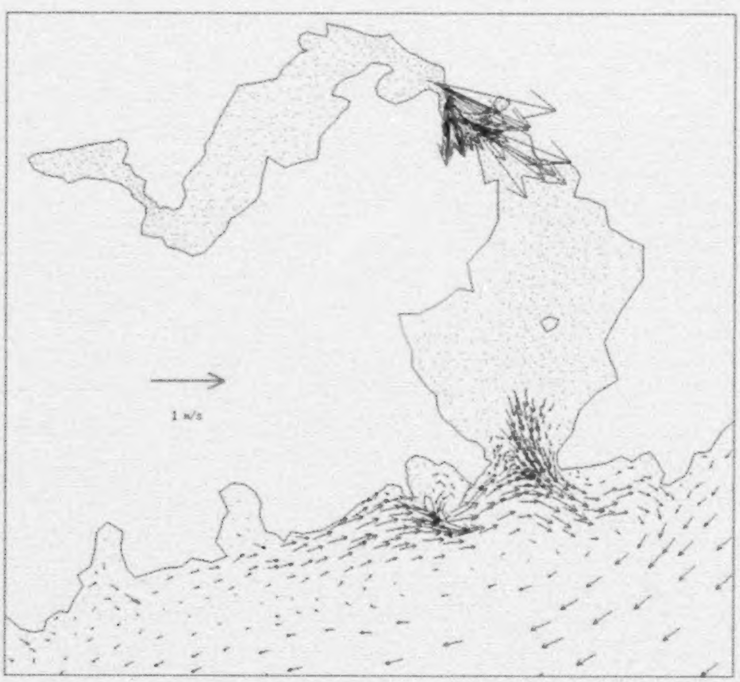


Figure 14. Preliminary FVCOM model predictions of water currents in the Musquash area with example predictions at one point in time.

Research Recommendations

Future work should include:

- continued monitoring of river water levels and freshwater discharge rates into the MPA estuary;
- development of stage-discharge relationships (minimum of 12 corresponding stage-discharge measurements;
- continuation of irregular/opportunistic measurements of MPA environmental characteristics such as water temperature, salinity, turbidity, dissolved oxygen and light penetration. This includes taking measurements during the annual Musquash Paddle;
- continued development of the water circulation model for the Musquash area. If desired, there is the potential to use the circulation model to develop an ecosystem model (e.g., dissolved oxygen, nutrient-phytoplankton-zooplankton, sediment transport), including assessing the influence of freshwater input; and
- continued effort/desire to install continuously recording instruments at strategic locations to monitor water parameters including temperature, salinity, turbidity, light and dissolved oxygen. This will require an approach that is not susceptible to equipment theft.

Other Relevant Concerns

The indicators will be useful in assessing whether the physical characteristics of the ecosystem are changing, but only if the data can be collected in a moored, time series approach. These temporal variations will be critical to determining and interpreting patterns in many of the chemical and biological variables within the MPA.

SEDIMENTS

Author: B. Law

The grain size of bottom sediments holds a record of the physical and biological processes at play during their formation (Kranck and Milligan 1985, Kranck et al. 1996; Curran et al. 2004). Resolving grain size characteristics can lead to greater understanding of the depositional or erosional history of an area and how perturbations to that area, either natural or anthropogenic, can change the seabed. The importance of the seabed as a source for food, habitat, and/or spawning ground is well documented. Therefore, having a baseline dataset of the surficial grain size is warranted.

Available Dataset and Data Collection

To date most of the sediment sampling has been opportunistic. Bottom sediment samples collected by A. Cooper as part of his benthic biodiversity work have been analyzed for grain size. Twelve samples collected in February 2010 and twenty-eight samples collected in August 2010 were analyzed using a Coulter Counter Multisizer IIe following the protocols of Kranck and Milligan (1979) and Milligan and Kranck (1991) (Figure 15). These samples were collected using a Hunter Simpson grab and are a homogenized mixture of the top 5 cm of bottom sediment.

Three bottom core samples were collected in December 2009 (Figure 16). Cores 1 and 2 were approximately 70 cm long with the third core being 35 cm in length. All cores were collected with a benthos gravity core using a 2.5 inch core liner. Cores were sectioned every 1 cm down to 20 cm, followed by sectioning every 2 cm to 50 cm depth and then every 5 cm thereafter. Sectioned core samples were processed and analyzed using geo-chronologies (^{210}Pb, ^{137}Cs) to determine sedimentation rate and down-core trace metal concentration. Radio isotope dating was performed by the Atlantic Environmental Radioactivity Unit (AERU) at the Bedford Institute of Oceanography (BIO). Trace metals analysis of 32 metals was performed at Research Productivity Council (RPC), Fredericton, NB using a total hydrofluoric acid (HF) digestion and analysis using Inductively-Coupled Plasma Mass Spectrometry. The trace metals that were

analyzed were: Aluminum, Antimony, Arsenic, Barium, Beryllium, Bismuth, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lanthanum, Lead, Lithium, Magnesium, Manganese, Molybdenum, Nickel, Potassium, Rubidium, Selenium, Silver, Sodium, Strontium, Sulfur, Tellurium, Thallium, Tin, Uranium, Vanadium, and Zinc.

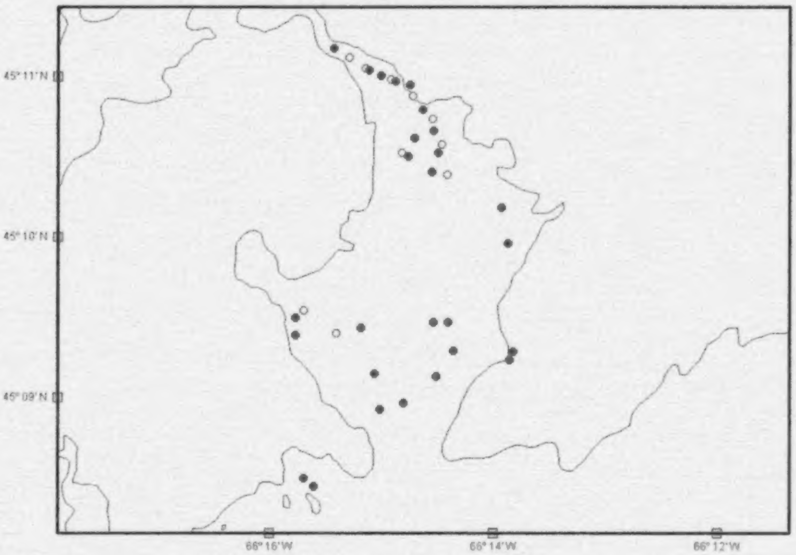


Figure 15. A plot of bottom sediment samples collected and analyzed for grain size. Samples were collected for benthic biodiversity work and represent the homogenization of top 5 cm of the seabed. Yellow dots represent samples collected in February 2010 while blue dots are representative of samples collected in August 2010. Locations that appear to be on land are actually collected in the MPA but may be exposed at low water.

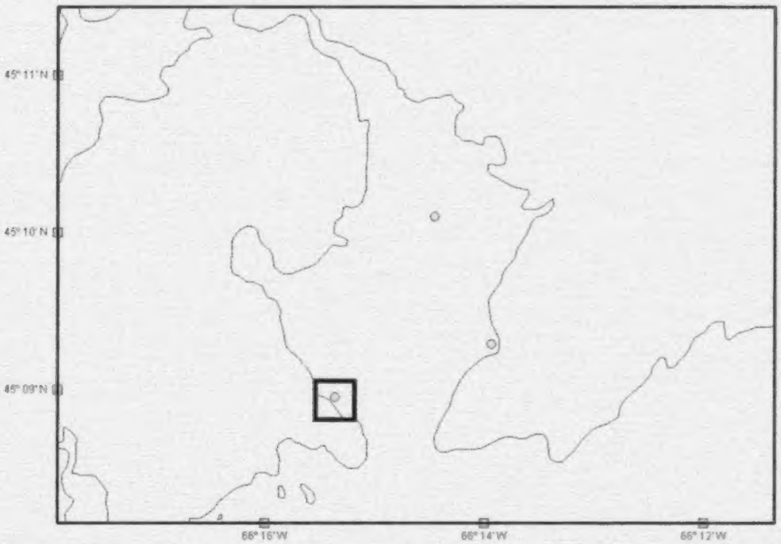


Figure 16. A plot of the three core stations collected for geochronology and trace metal analysis. The station encompassed by the black box is core station two where a sedimentation rate of approximately 0.5 cm/year was determined.

In November 2012, 10 stations were sampled for bottom sediments using an Eckman grab and slo-corer. The top centimeter (cm) of bottom sediment from each station was analyzed for trace metals using the same lab and protocols listed above. In addition, four core samples taken with the slo-corer were sectioned and analyzed down to 10 cm depth. These samples were focused in and around the river mouth just south of Cheeseman's Beech in response to an environmental spill at the Coleson Cove, NB, power plant (Figure 17). The Eckman and slo-corer were used to compare differences in sampling techniques and trace metal results. All analyzed samples had trace metal values below or at background levels. It is recommended that a slo-corer or device that preserves the sediment water interface be used to sample bottom sediment for trace metals. This interface is where freshly deposited material resides and can contain high trace metal concentrations that are easily transported (Milligan and Law 2013).

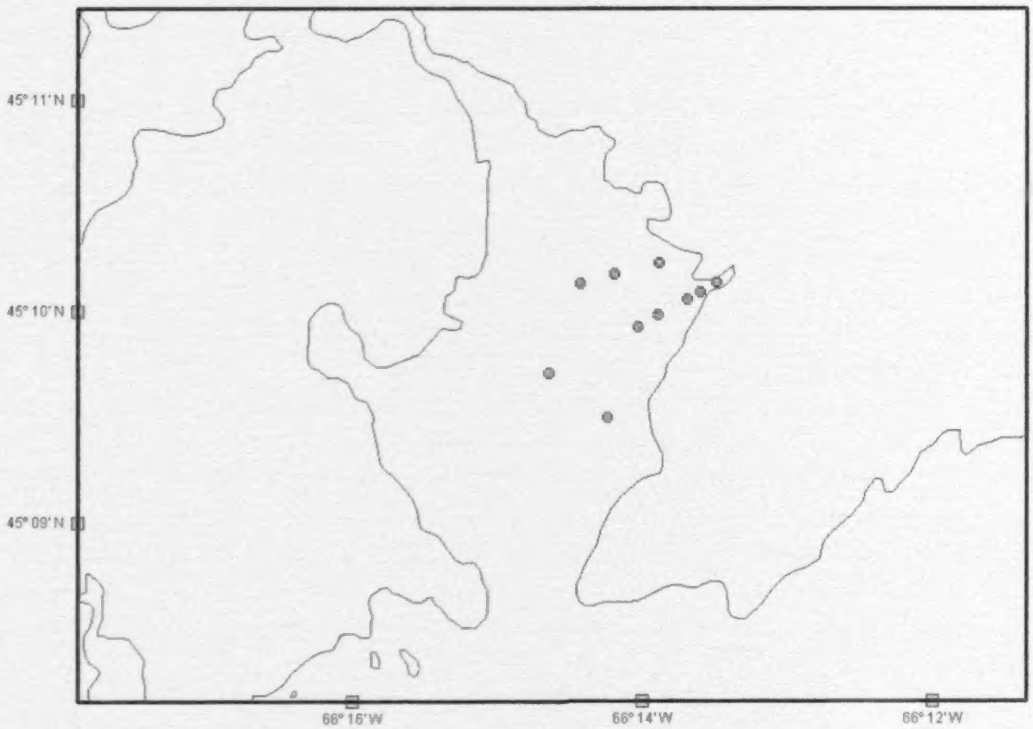


Figure 17. A plot of the stations occupied for surficial sediment collection using an Eckman grab and also sampled using the slo-corer. Samples were analyzed for trace metal concentration in response to the Coleson Cove power plant spill.

Features of Existing Time Series

The trace metal data from surficial and down-core samples represent a reliable baseline dataset (Figure 18). Although coverage does not encompass the entire marine section of the MPA, to date all data are at background values. An increase in metal concentrations above background levels could trigger further monitoring or research into the cause of the increase.

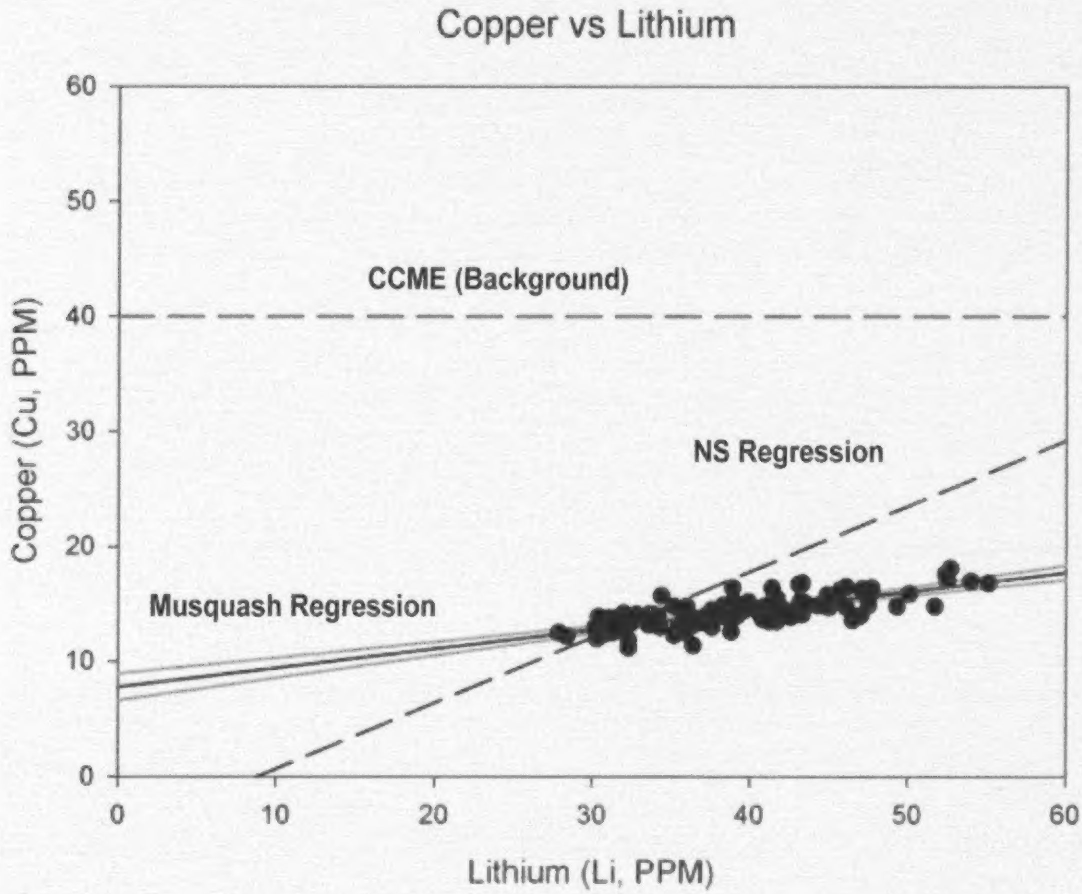


Figure 18. A plot of Copper (Cu) versus Lithium (Li) for all samples analyzed from the three cores collected in 2009. Canadian Council of Ministers of the Environment (CCME) background value for copper for marine sediment is 40 ppm and marked with a red dashed line. All samples fall below this threshold value. The regression line marked with a dashed black line was determined by Yeats et al. (2005, 2011) using samples analyzed from NS. The two green lines and straight black line represent the regression and 95% confidence intervals based on the samples collected and analyzed from the MPA.

The surficial grain size data from the MPA is incomplete. Bottom sediments samples and subsequent grain size distributions, obtained using the samples collected by A. Cooper, represent several centimeters (top 5 cm) of the seabed. Based on work by J. Smith and others of AERU that showed sedimentation rates to be on the order 0.5 cm/year (Figure 19), these samples represent approximately a decade of sedimentation in the MPA. It is, therefore, recommended that a surficial grain size survey be completed in the MPA, with the grain size analysis of the top 0.5 cm of the seabed acting as a baseline to assess seabed change with time.

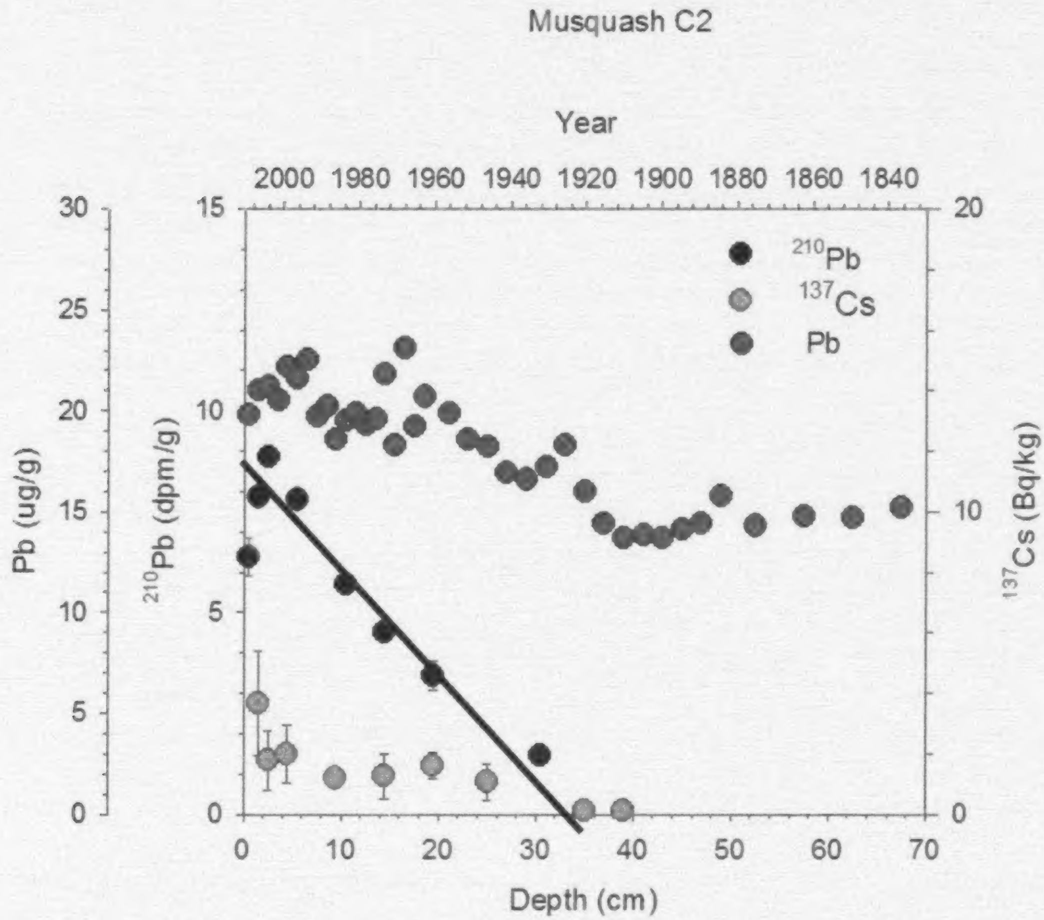


Figure 19. A plot of the downcore geochronologies (^{210}Pb and ^{137}Cs) from core 2 collected in the MPA. The black line represents the timeline used to calculate the sedimentation rate that is roughly 35 cm of deposition in 70 years, which translates to approximately 0.5 cm/yr, a number which is consistent with other bays and estuaries from New Brunswick (NB) and Nova Scotia (NS). Blue dots represent the Lead (Pb) trace metal concentration with depth and time downcore.

Baseline Values

The Canadian Council of Ministers of the Environment (CCME) provides background concentration values for certain trace metals in the marine environment. At present, trace metal concentrations of bottom sediments collected in the MPA are at or below CCME background values; thus, these concentrations could serve as baseline values for the MPA. In addition to the CCME guidelines, Lithium normalization (Li), a normalizer for grain size and a way to predict anthropogenic influence to the metals concentration in the sediments, can be used (Figure 18). Regressions using Li appear to be different when comparing sediments collected in bays and estuaries in NS versus NB (Figure 18). To ensure consistency in the measurements, it is recommended that the same protocols are followed when analyzing for trace metals in bottom sediments. For complete details of Li normalization, refer to Yeats et al. (2005, 2011).

Reference Points

Although it is unfeasible to re-occupy and sample the bottom sediment at every station for trace metals, it is recommended that four to five stations be occupied yearly as part of a long term monitoring program. Stations should be located throughout the MPA with consideration given to

the three stations previously occupied for down-core trace metal concentrations and geochronology analysis (Figure 16), as well as the series of stations occupied near the river mouth as part of the Coleson Cove spill response (Figure 17).

It is recommended that stations sampled for surficial grain size are examined every three years to determine if environmental factors, such as changing currents, storm events, biological activity or anthropogenic activity, are changing the landscape of the seabed. Areas of deposition or erosion could be determined, and possible links to changing habitat productivity could be made.

Research Recommendations in Support of Monitoring

It is recommended that a complete surficial grain size survey be completed. This baseline dataset will allow for the creation of a surficial habitat map. Subsequent change to seabed texture can then be determined. It is also recommended that a subset of the sample stations used to complete the seabed habitat map be occupied twice during the first year to determine spatial and temporal dynamics.

Other Relevant Concerns

All grain size data should be used in comparison to hydrodynamic model output. Median grain size data can be predicted based on the average shear stress exerted by currents and waves on the seabed. It is, therefore, practical to compare modelled output of shear stress with median surficial grain size. If there are correlations between the model output and grain size, then it is possible to predict change to the bottom substrate in scenarios, such as sea level rise, due to climate change where current velocities are predicted to increase. The effect of waves will also be required to be included in the hydrodynamic model for accurate prediction in shallow water.

PHYTOPLANKTON

Author: J. Martin

Very little phytoplankton sampling, other than a few samples collected on an opportunistic basis, has been completed in the Musquash region through the years. In June 1999, samples collected from the Estuary showed high concentrations of detritus in the inner Estuary, and other samples had 29 different species of phytoplankton (Singh et al. 2000). Results from samples from the same period taken at regularly sampled monitoring sites (Lime Kiln Bay, Deadmans Harbour, Wolves Islands, mid-Passamaquoddy Bay and Brandy Cove – Figure 20) revealed the same species, but fewer cells were detected in Musquash (Martin et al. 2006). Although few samples have been collected from Musquash, results from the regular long term phytoplankton dataset in the southwestern New Brunswick portion of the Bay of Fundy could be applied to give an estimate of populations and species composition and abundance for Musquash.

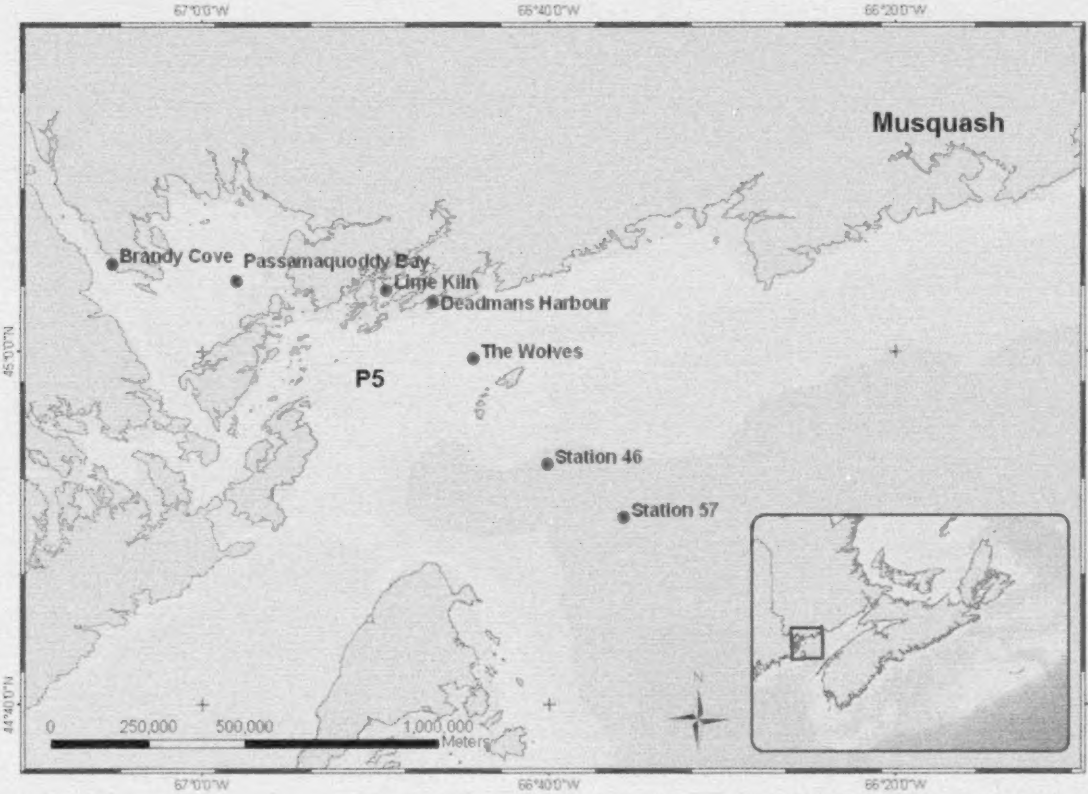


Figure 20. Phytoplankton monitoring stations in the southwest portion of New Brunswick, Bay of Fundy including P5 (Prince 5), a station that is monitored monthly as part of the Atlantic Zonal Monitoring Program (AZMP).

Available Dataset

Presently, there is a long term phytoplankton monitoring program in the Bay of Fundy that was initiated in southwest New Brunswick in 1988 in response to a rapidly growing aquaculture industry and concerns about environmental impacts and harmful algal blooms (HABs). The objectives of the phytoplankton study when it was initiated were: to establish baseline data on phytoplankton populations since little detailed work had been published since studies by Gran and Braarud (1935); to identify harmful algal species that could potentially cause harm to the aquaculture industry; to provide an early warning for harmful algal blooms to the aquaculture industries by sorting and identifying samples soon after collection; and to determine patterns and trends in phytoplankton populations. Another purpose of the study was to determine whether there were environmental changes, such as changing trends in phytoplankton populations or nutrient loads. In addition, it could provide an early warning to regulatory agencies such as the Canadian Food Inspection Agency (CFIA) for the occurrences of species that produce toxins resulting in shellfish toxicities and closures of shellfish beds to harvesting.

Data Collection

Sampling at the Wolves Islands, Deadmans Harbour, Lime Kiln, Passamaquoddy Bay, and Brandy Cove occurs at weekly intervals between April and late October and monthly during winter months resulting in approximately 660 total visits for each site from 1988- 2012. Sampling at the regular sites includes phytoplankton species abundance, nutrients, secchi depth and CTD casts.

Phytoplankton and nutrient samples are collected at the surface by bucket from all five stations and at depths of 10 m, 25 m, and 50 m with a Niskin bottle at the Wolves station. During the summer months, a 10 m vertical plankton haul is made with a 20 µm mesh net, 0.3 m in diameter. A subsample is preserved with formalin:acetic acid (1:1 by volume) for further phytoplankton identification. In addition, a live sample is kept cold and examined with a compound microscope. Later, 50 ml subsamples are settled in Zeiss counting chambers for 16 hours. All phytoplankton greater than 5 µm are identified and enumerated (as cells$\cdot L^{-1}$) with the Utermöhl technique using a Nikon inverted microscope (Sournia 1978).

Features of Existing Time Series

Unfortunately, this particular dataset does not include a sampling site in Musquash. If additional coverage is thought to be beneficial, an additional sampling could be added at Musquash on an occasional basis for comparison with the regularly monitored sites. However, logistics would need to be examined because without regular weekly sampling, there would be gaps in both species composition and abundance as phytoplankton populations can change on a weekly basis.

Phytoplankton data from the long term time series represent a reliable dataset for Bay of Fundy baseline data (Wildish et al. 1988, 1990; Martin and LeGresley 2014, Martin et al. 1995, 1999, 2001, 2006, 2014a, 2014b).

There are apparent strong seasonal patterns in the total phytoplankton community and the diatom and dinoflagellate components, with peak abundance generally in July for the dinoflagellates and August for the diatoms. Total numbers of diatoms, dinoflagellates, and "other" species, that include silicoflagellates, ciliates and small zooplankton, have been increasing since 1988 and are significant (<0.01) (Figure 21). The ratio of diatoms:dinoflagellates appears to be decreasing slightly but is not significant (Figure 21).

Analysis of abundance for most species from the 22 year period (1988-2011) indicates that cell abundance from one year does not reflect the following year and there is a significant amount of interannual variability. Figure 22 shows an example of inter-annual variations between total phytoplankton, diatoms, dinoflagellates and "other" organisms from 2007-2012 at the Wolves Islands.

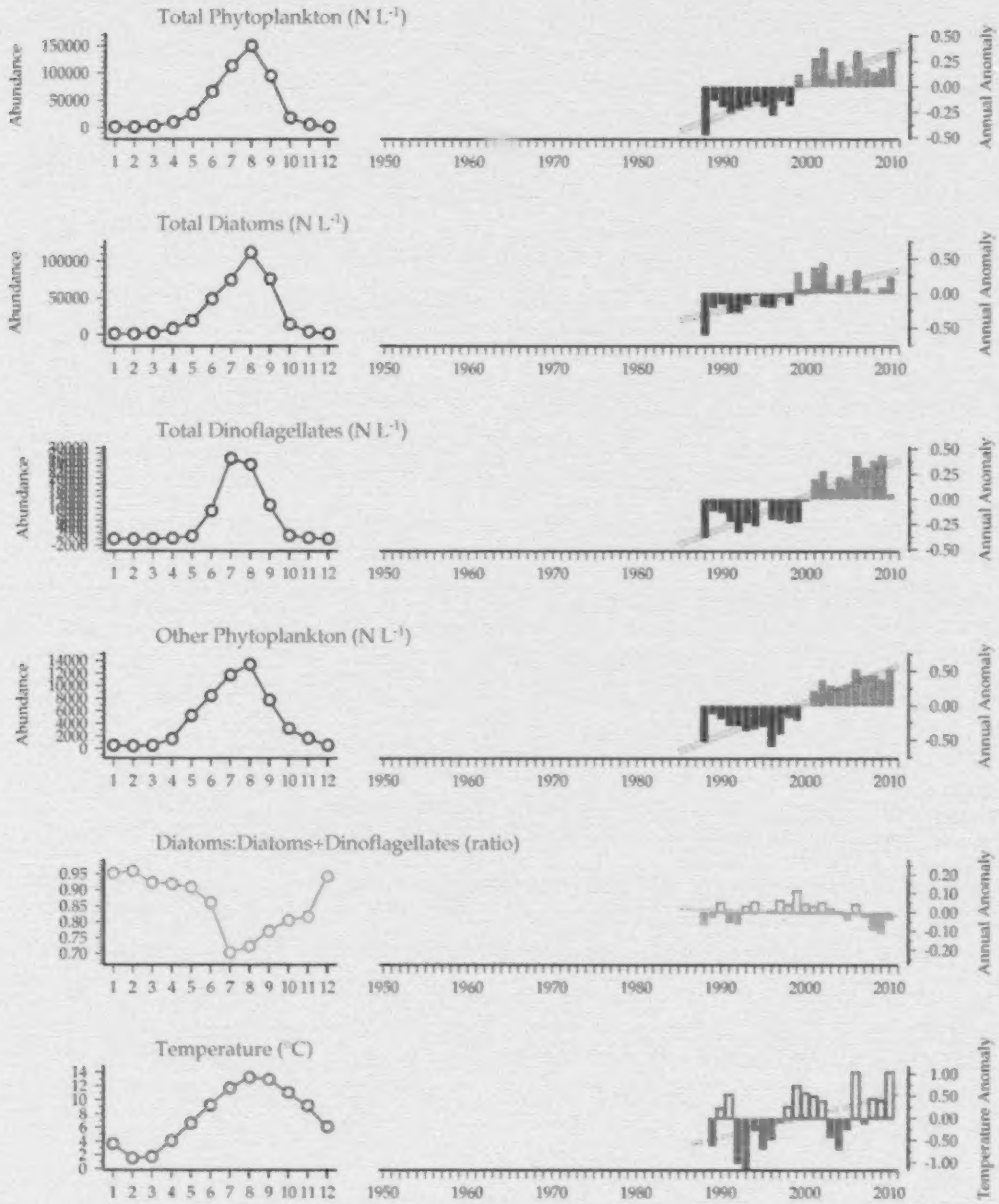


Figure 21. Multi-year changes in diatoms, dinoflagellates and "other" species (silicoflagellates, ciliates, and smaller zooplankton) from total pooled values from all monitoring sites.

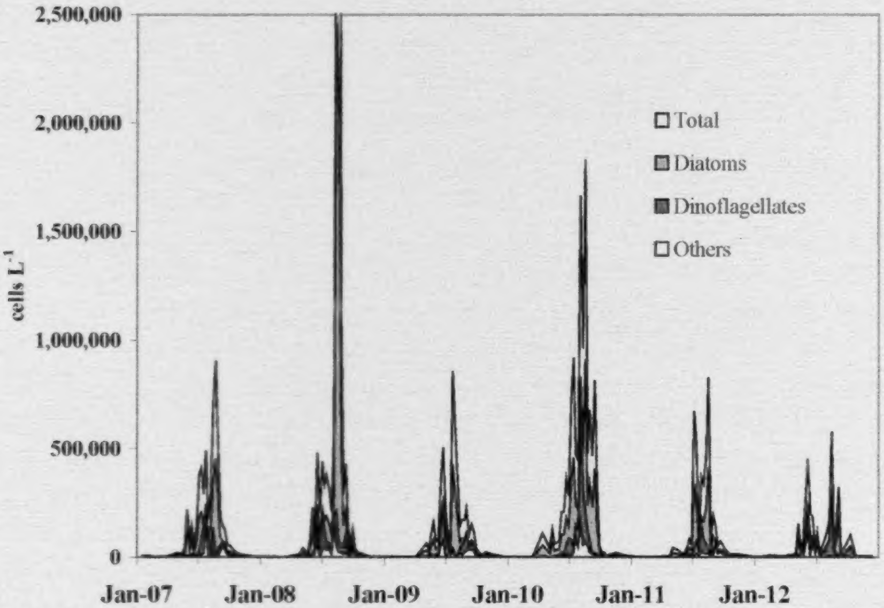


Figure 22. Densities of total phytoplankton, diatom, dinoflagellate and "other" species at the Wolves Islands (2007-2012).

Baseline Values

To date, there are 169 diatom species (including 61 genera), 67 dinoflagellates (17 genera) and 26 smaller zooplankton, silicoflagellates and ciliates observed in the Bay of Fundy.

The current phytoplankton dataset is extensive enough to show 36 new phytoplankton species in the region. Species were defined as "new" if they had not been observed in samples prior to 1995 and now appear to be permanently established (observed during more than one year or annually since the time of first detection) as members of the local ecosystem. The new species to the area include the following: (dinoflagellates) *Alexandrium pseudogonyaulax*, *Amphidinium carterae*, *Amphidinium sphenoides*, *Ceratium macroceros*, *Ensiculifera carinata*, *Gonyaulax alaskensis*, *Polykrikos schwartzi*, *Preperidinium meunieri*, *Protoperidinium americanum*, *Protoperidinium crassipes*, and *Pyrocystis lunat;* (diatoms) *Attheya septentrionalis*, *Attheya longicornis*, *Chaetoceros peruvianus*, *Chaetoceros radicans*, *Cylindrotheca gracilis*, *Grammatophora serpentina*, *Lithodesmium undulatum*, *Mediopyxis helysia*, *Membraneis challengeri*, *Meridion circulare*, *Neodenticula seminae*, *Odontella sinensis*, *Proboscia eumorpha*, *Pseudo-nitzschia subpacifica*, *Pseudo-nitzschia fraudulenta*, *Pseudo-nitzschia heimii*, *Pseudo-nitzschia lineola*, *Pseudo-nitzschia turgidula*, and *Thalassiosira punctigera*, *Urosolenia eriensis;* and ("other") *Apedinella* sp., *Chrysochromulina parkeae*, *Commation cryoporinum*, *Microcystis* sp., and *Phaeocystis pouchetii* (Martin and LeGresley 2008, 2014; Martin et al. 2014a, 2014b). Most of these species are cold temperate species that tend to exist in many regions of the world with similar ecosystems to the Bay of Fundy.

Reference Points

Earlier work indicates that cell densities from Musquash tend to be lower than most other areas in the Bay of Fundy. This suggests that harmful algal species and high biomass blooms would be less of a potential threat in that particular area.

Recommendations in Support of Monitoring

It is recommended that occasional samples be taken from Musquash and compared with earlier samples and those obtained through the long term monitoring program.

Other Relevant Concerns

Some phytoplankton blooms in the Bay of Fundy are initiated in the inshore, whereas others are initiated in the offshore regions; each species is also unique. When/if applying phytoplankton results from other areas in the Bay of Fundy to the Musquash area, the conditions that favor vegetative growth, mechanisms for the dispersion and transport of cells, how different life cycle stages behave in the dispersion and retention of motile cells, and the importance of climate, oceanographic conditions, and weather need to be considered.

BENTHIC BIODIVERSITY

Author: A. Cooper

Benthic macro fauna (bottom-dwelling organisms greater than 500 um) are an important ecological component within a tidal estuary such as Musquash. Many of the species that make up this component are small in size but very numerous. As a community, they provide an important ecosystem function. They play a role in nutrient capture from filtering the water column; the utilisation of dead and decaying material that settles to the bottom; habitat enhancement and stabilization through burrowing; and provide a food source for larger organisms such as crustaceans, fish, and birds (Boesch et al. 1976). The natural cycles of tide, freshwater inputs, and seasonal changes in temperature, means that temperate tidal estuaries are typically subject to extreme environmental conditions. The community of organisms that inhabit the benthic zone are perhaps less subject to these extreme conditions when compared to the water column or shoreline (Boesch et al. 1976), which could suggest that benthic communities are considered a good candidate for monitoring changes within the MPA.

Available Dataset

The available data contain a geo-referenced list of species and total abundance of benthic macrofauna, which are predominantly small infauna species (> 500 um) from all sample stations (Figure 23). Sampling occurred on five separate dates over a three-year period from February 18, 2010, to September 21, 2012.

Data of associated sediment characteristics (grain size, organic content) have not yet been created as the sediment analysis is on-going.

Data Collection

The sampling protocol is unique for the Musquash MPA, although similar protocols have been used to study benthic community structure around several aquaculture cage sites within the Passamaquoddy Bay area of the Bay of Fundy (Chang et al. 2011). The sampling area was limited to the lower portion of the Musquash MPA downstream of Five Fathom Hole to the mouth of the harbour. A stratified sampling design was implemented to sample three ecological zones within this lower portion (Figure 24). These zones (strata) were: intertidal area (mudflats) that are typically exposed during low tide, the subtidal area that is never exposed during low water, and the narrow channel, which is a natural bathymetric feature that periodically or continuously contains moving water, has a definite bed, and has banks (often submerged) that serve to confine the flow of water. On each sampling date, ten stations were haphazardly chosen per strata for a total of 30 stations.

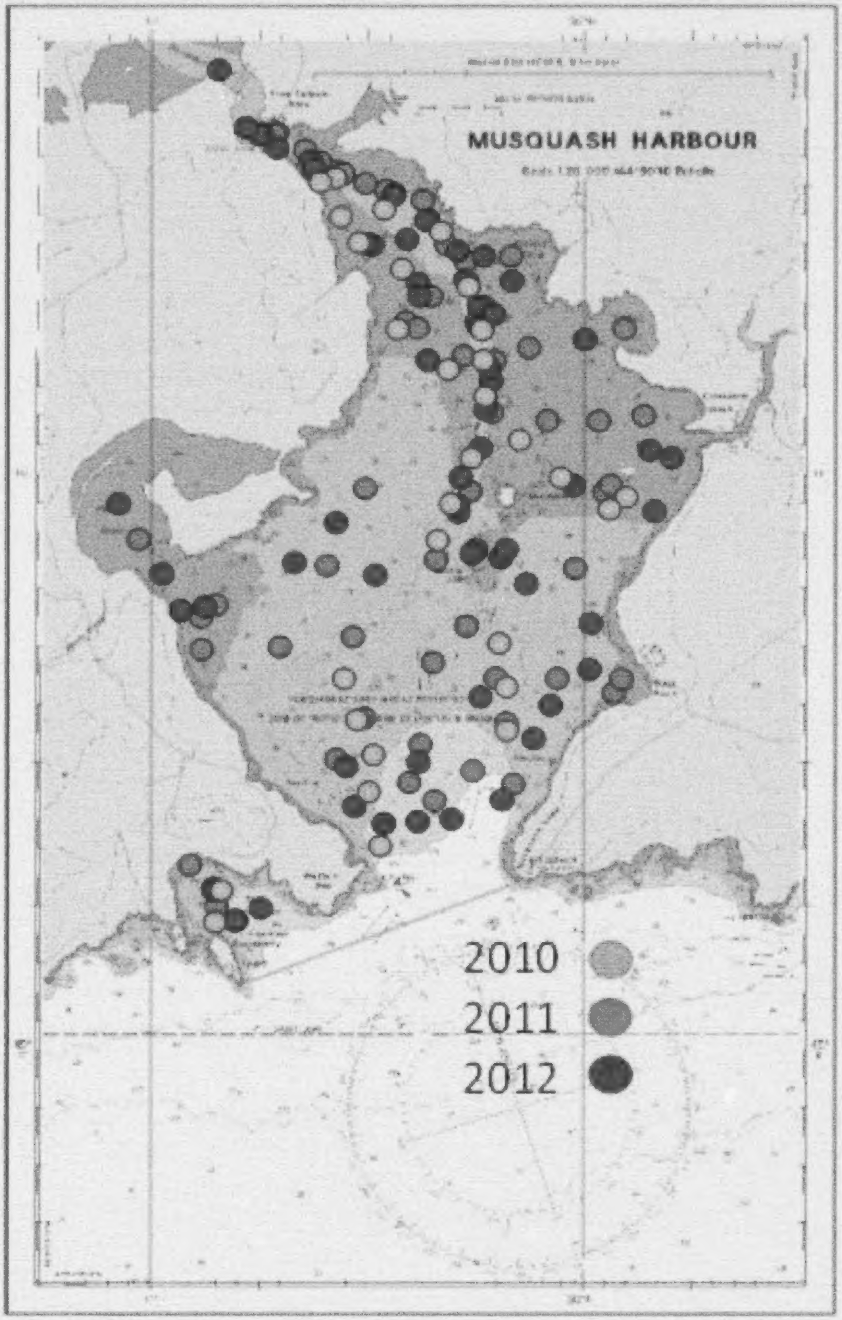


Figure 23. Map of the Musquash Estuary and Harbour indicating the location of all benthic grab stations sampled from 2010 to 2012.

All benthic sediment samples were collected using a Hunter-Simpson grab, which collected 0.024 m^2 of sediment (16 X 15 cm) and was designed with a protective cover to minimize disturbance to the sediment surface layer. A small grab was used because it could be deployed from a smaller vessel (7.3 m in length) that could easily maneuver within the relatively narrow confines of the Musquash channel and over the shallow intertidal waters of the estuary. Depending on the sediment composition, the grab was able to sample the top 4 to 15 cm of

sediment, to a maximum volume of 1500 ml. Triplicate grab samples were taken at each station within a few meters of each other.

The wet weight of all grabs was recorded to the nearest gram, and a subsample of approximately 50 g of material was taken and frozen for subsequent analysis of grain size and organic content. All samples were sieved to retain the biological components greater than 500 um. Triplicate samples were combined and fixed in a 5-10% buffered formalin solution for 5-7 days, rinsed with freshwater for 2-5 days, and then stored in 50% isoproponal until species are identified. All organisms were identified to the lowest taxon (usually species) and enumerated. The number of taxa and number of individuals (abundance) were standardized by the combined total grab wet weight per station.

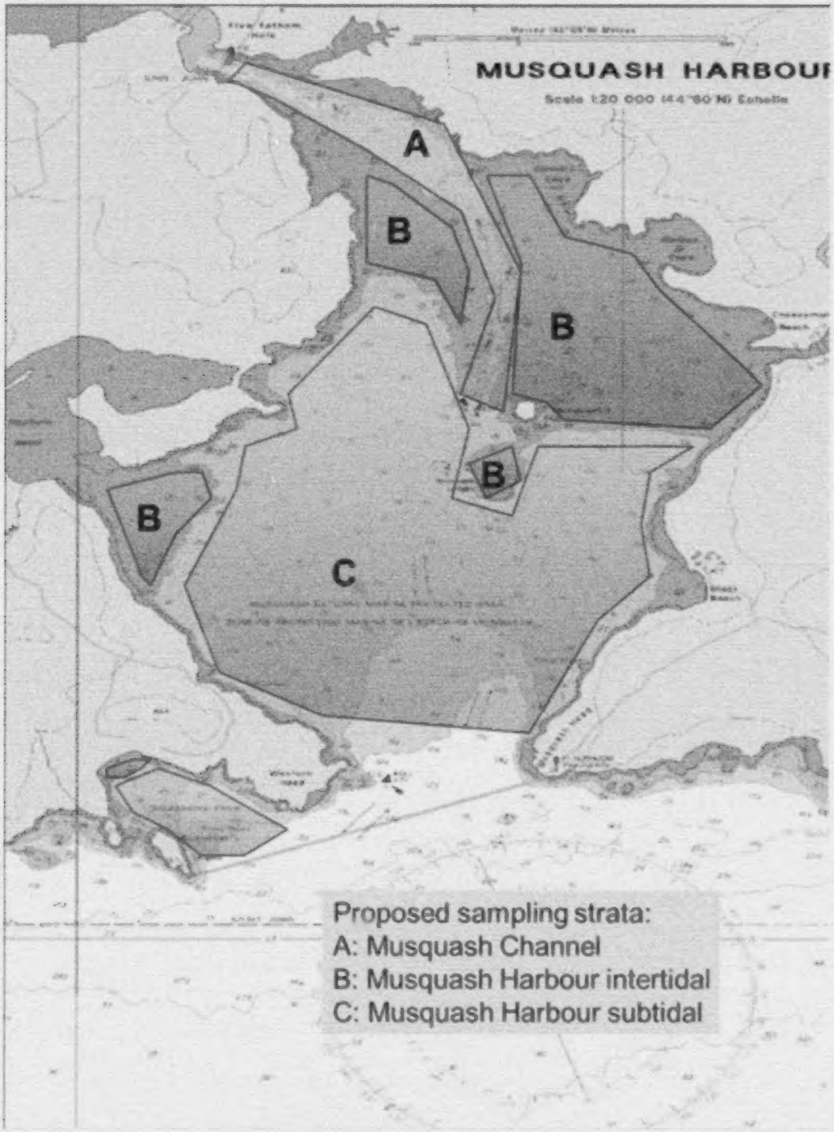


Figure 24. Map of Musquash Harbour south of Five Fathom Hole illustrating an approximation of the three proposed sampling strata: A. Musquash Channel, B. Musquash Harbour intertidal, C. Musquash Harbour subtidal.

Recommended Analysis

Both the number of taxa and the number of individuals per station are positively correlated with sample weight. Abundance (number of individuals) can be standardized by the total wet weight of the grab prior to further analysis (i.e., no. of individuals per kg). The number of taxa cannot easily be standardized prior to calculating most estimates of species richness or diversity. Therefore, the total weight of the pooled sample should be considered when comparing changes in the number of taxa both spatially (strata) and temporally (year, season). A plot of log abundance on rank (Figure 25) is an essential first step to evaluate the form of the data and to determine if there are any anomalies with respect to abundance of dominant species from one sampling period to the next (Seaby and Henderson 2006). This analysis revealed that the data follow a log series distribution, which is an important criterion for the calculation of many biodiversity indices (Seaby and Henderson 2006). This plot also revealed a very high abundance of dominant species within the 2010 winter intertidal sample (top grey line labelled as 2010.w.i). This difference was determined to be a result of three samples with an unusually high number of dominant taxa. These samples were considered statistical outliers that were subsequently removed from the analysis.

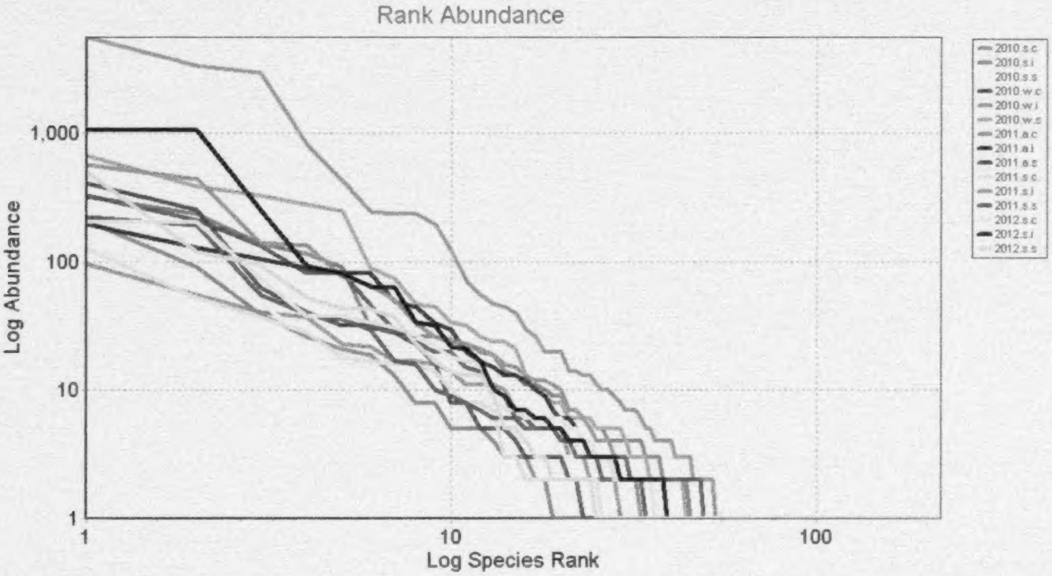


Figure 25. Rank abundance plot of log abundance versus log species rank for all samples sub-categories year, season, and strata.

To determine if benthic sampling is representative of the species community that can be observed under a specific sampling regime, species rarefaction curves are used to assess the rate at which new species are discovered for each additional sample taken. When the rate of accumulation approaches or reaches an asymptote (zero slope), the sample is considered sufficient to provide a reasonable estimate of species richness (Seaby and Henderson 2006). Estimates of species richness (SMax) and Alpha diversity are one dimensional indices that can be easily calculated through several methods but with perhaps limited utility at this stage until the natural community structure is better understood through the following recommendations.

An initial review of the Musquash Estuary MPA monitoring data (DFO 2013) recommended a study of taxonomic relatedness and niche modelling to increase the understanding of the functional role of species assemblages and how they change spatially and over the sampling

period (Carranza et al. 2011; Clarke and Gorley 2006). It was also recommended that correlations between species diversity and environmental variable, such as sediment grain size, organic content, and seasonal hydrographic conditions, should be examined to ascertain if samples taken at different times were collected on similar habitat types and, therefore, comparable; to determine how habitat variability naturally influences species diversity; and to possibly establish an environmental variable (perhaps more easily monitored) that could serve as a proxy to species diversity (DFO 2013).

Features of Existing Time Series

A three year time series, originally planned to establish a baseline for monitoring benthic diversity, was incomplete due to missed sampling periods primarily caused by poor weather conditions (Table 2). Only the summer sampling season was successfully performed for all three years.

Table 2. List of planned and successfully completed sampling days.

Year	Winter	Summer	Autumn
1	18 February 2010	18 August 2010	-
2	-	1 September 2011	14 December 2011
3	-	21 September 2012	-

Note: Cells marked by a dash (-) indicate missed sampling periods due to poor weather conditions.

In addition, the time series has not yet accounted for bias that may be associated with habitat characteristics such as sediment grain size and organic content. However, this can be achieved through the recommended analysis indicated in the previous section. In this document, it is assumed that ecological strata, pre-assigned in the sampling design (Figure 24), are naturally different from each other and that each strata was sampled similarly from year to year and among seasons. The species composition is assumed to be naturally influenced by the hydrographic differences among strata that were described above. Subsequent analyses and continued monitoring must consider this minimum level of data classification as a potentially important factor in measuring species diversity. Any trends or lack of trends with the current time series are presented under the assumptions that the habitat sampled within strata was similar among years and seasons. These assumptions have not yet been fully tested and, therefore, trends should be interpreted with care until the validity of the assumptions has been assessed.

Total number of taxa observed for all sampling periods combined was 212, and the estimate of species richness (SMax) through sample interpolation was 212 (+/28) (Figure 26). The rarefaction curve predicts an asymptote of 212 species at 170 samples. This suggests that the 147 samples that are included for this time series were sufficient to capture the species community for the sampling area using this method and time frame.

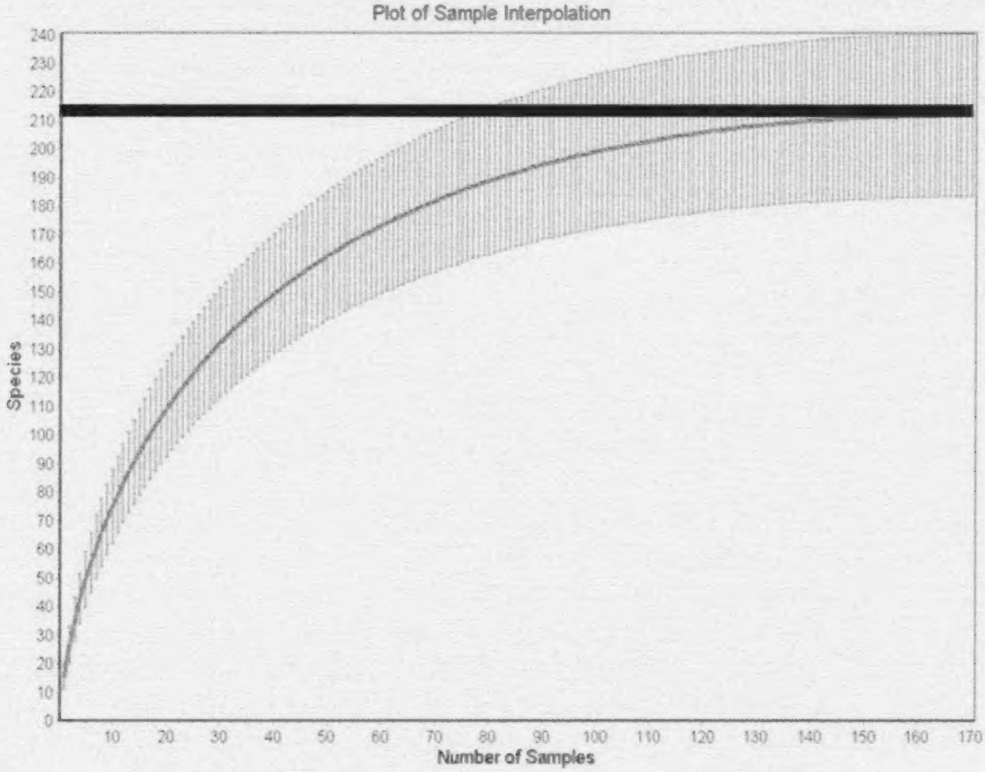


Figure 26. Species rarefaction curve for all samples combined (n=147) illustrating an estimate of species richness through sample interpolation of 210.8 (+/- 28) based on a plot of species accumulation using 100 random samples of the dataset.

Specimens that were damaged during collection and sample processing or in a larval form were typically not identified to species. This resulted in the recorded number of taxa being slightly higher than the true number of species in the sample. For example, some material may only be recorded to genus yet contain species that have also been identified within the sample. This overestimate in the number of taxa in the dataset can be accounted for by analyzing trends in the data at different taxonomic levels. A list of different species richness estimates (Table 3) illustrates that different methods can produce different estimates for SMax. The important consideration for this will be to ensure that analysis of trends in species richness is based on a comparable dataset, methodology, and index.

A list of the top ten most prevalent species for the entire sample and by strata (Table 4) indicates that the intertidal zone contains the highest average number of individuals per kilogram of sediment and that the three strata are notably different in the composition of their most dominant species.

Species accumulation at the lowest data subset (e.g., 2010, summer, channel) were insufficient to be confident that the number of taxa observed (13 taxa, n=10) is representative of the community estimate (SMax=52) through sample interpolation (Figure 27). Note that the slope of the rarefaction curve is still positive for the actual number of samples that were taken (n=10). This suggests that more taxa would be observed through additional sampling of this area. Subsequent diversity analysis should consider pooling of samples by year, season, and/or strata in order to investigate trends and changes in species composition.

Table 3. List of estimates for species richness (SMax) of the entire time series from 2010 to 2012.

Estimate	SMax (+/-sd)
Taxa observed	212
Heterogeneity (Coleman)	211.1
Chao Quantitative	217.9 (+/- 2.594)
Chao and Lee 1	210.6
Chao and Lee 2	211.2
1st Order Jackknife	226.9 (+/- 9.163)
2nd Order Jackknife	192.5
Bootstrap	225.9
Michaelis-Menten	227.6
Pooled Rarefaction	205.3
Henderson	211.1
Sample Interpolation	210.8 (+/-28.37)

Table 4. List of top ten species observed expressed as the average number of individuals per kilogram of sediment.

Lowest Taxon	Combined	Channel	Intertidal	Subtidal
Manayunkia aestuarina	129	-	177	-
Streblospio benedicti	88	6	208	-
Harpacticoida	81	-	187	39
Fabricia sabella	62	-	73	-
Amphiporeia lawrenciana	58	-	115	-
Paranais litoralis	36	-	36	-
Cossura longocirrata	28	21	-	42
Nematoda	23	12	46	-
Pygospio elegans	21	-	30	-
Hydrobia truncata	18	-	-	-
Tharyx sp.	-	14	-	-
Balanus crenatus	-	11	-	-
Pycnophyes frequens	-	9	-	18
Aricidea catherinae	-	7	-	10
Tubificidae	-	6	32	-
Cirratulidae	-	5	-	7
Levinsenia gracilis	-	5	-	-
Oligochaeta	-	-	33	-
Nucula proxima	-	-	-	20
Ostracoda	-	-	-	9
Axiothella catenata	-	-	-	9
Dyopedos porrectus	-	-	-	8
Scoloplos acutus	-	-	-	8

Note: Cells marked by a dash (-) indicate that the lowest taxon was not ranked within the top ten for the specific strata.

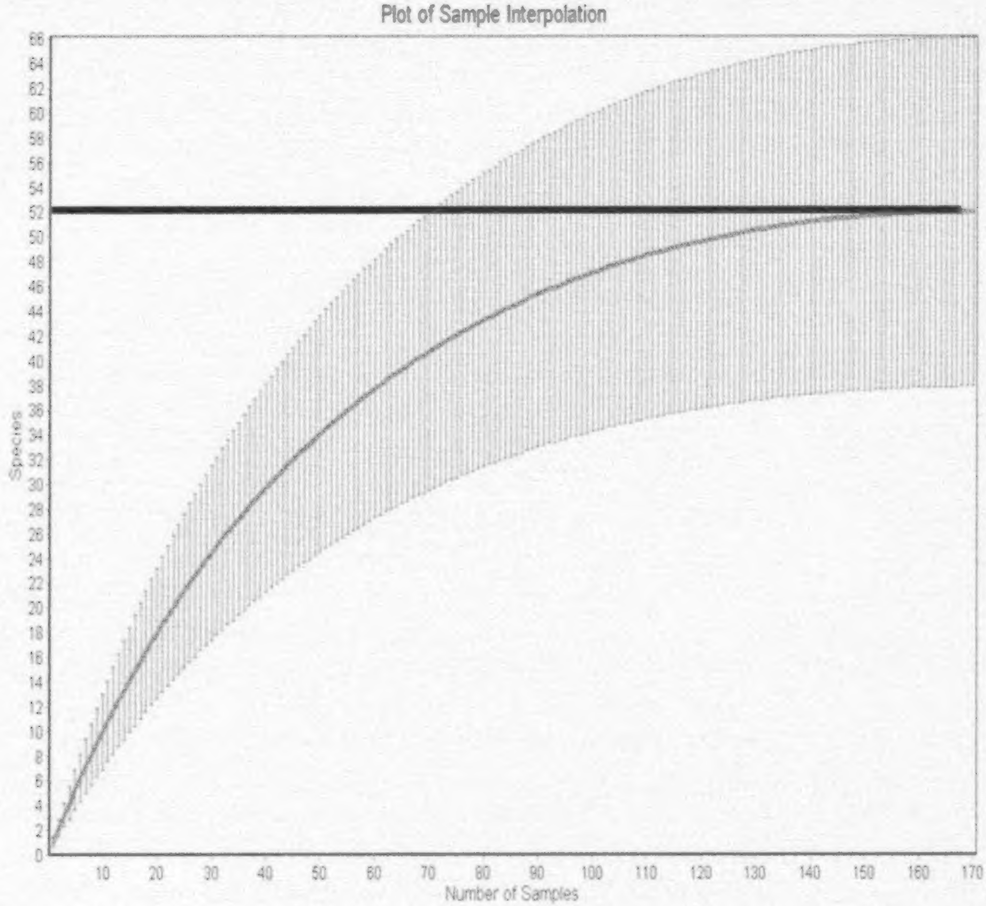
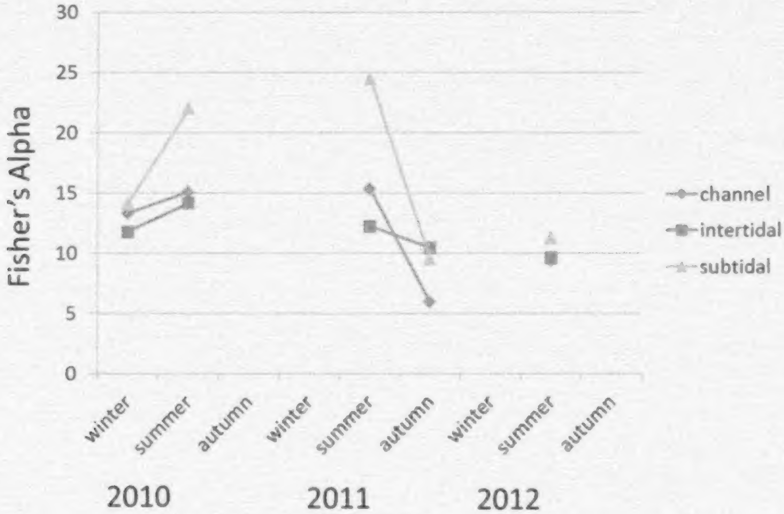


Figure 27. Species rarefaction curve for lowest data subset (2010, summer, channel) with estimate of SMax (52) through sample interpolation (n=10, interpolation based on 100 random samples).

There were indications of a seasonal trend in diversity observed by estimating the number of species that could be observed in a sample through Fisher's Alpha (Figure 28a). Although all three strata provide different estimates of Fisher's Alpha, the seasonal change appeared to follow the same trend (winter to summer increase in 2010, summer to autumn decrease in 2011). The subtidal zone would appear to be the most variable and the intertidal zone the least variable from year-to-year. This suggests that pooling strata within a season may not result in a loss of trend information for this index. However, employing a different index of diversity, such as the Berger-Parker dominance index (Figure 28b), indicates an opposite trend within the intertidal zone in 2011. In this instance, pooling strata would obscure this particular feature in the dataset. This serves to illustrate the uncertainties in simply reporting changes using one dimensional indices and the need to further investigate the ecological nature of these changes with respect to changes in dominant species, correlations with environmental variables and their ecological role.

a)



b)

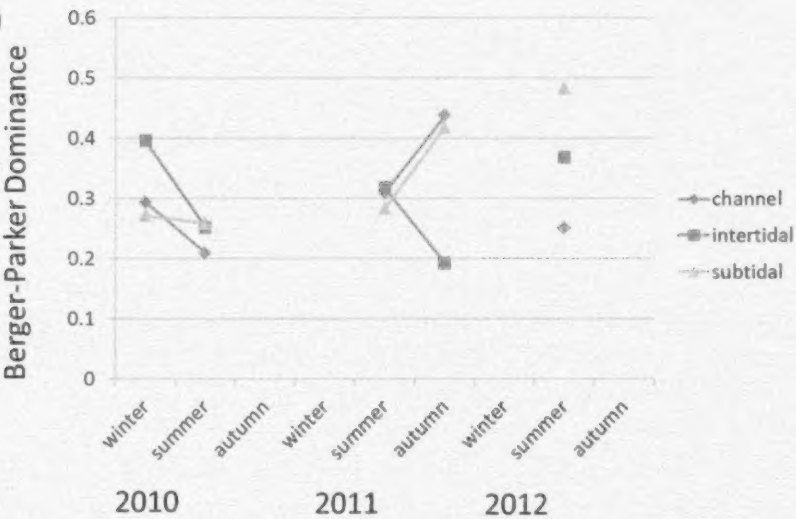


Figure 28. Seasonal trends in diversity indices estimated for the lowest data subset. Upper panel a) Fisher's Alpha, which represents the number of species in a sample represented by one individual. Lower panel b) Berger-Parker Dominance, which calculates the numerical importance of the most abundant species.

Baseline Values

Benthic species richness for the Musquash Estuary can be reported as a baseline of diversity with the understanding that monitoring change against this baseline will require an equivalent sampling effort with respect to area and time scale. A baseline of species richness (SMax) for the entire dataset are reported in Table 3. A list of most dominant taxa for the entire three year sample and by strata is reported in Table 4.

More informative baselines can be developed through an analysis of subsets of the information with respect to understanding natural variability over time and correlation against habitat characteristics (DFO 2013).

Reference Points

The objective of this study was to establish a baseline with an estimate of natural variability. Further analysis will be required to determine how biodiversity changes with environment in order to develop an informative reference point.

Research Requirements in Support of Monitoring

Additional research is required to investigate the potential influence from oceanographic and hydrographic change (or events).

The data collected is adequate to provide a baseline for on-going monitoring with respect to identifying or confirming species within three predefined habitat zones. If monitoring is to continue (i.e., on-going), it is recommended that the primary effort would be to sample during the summer season in order to supplement the three years of summer time series that have already been captured. This would establish a summer baseline with an improved estimate of annual variability. The data collected do not adequately capture seasonal variability due to insufficient number of sampling dates. Sampling within the Musquash Estuary during the autumn and winter has been logistically problematic from a small vessel, and it is recommended that a larger vessel be employed to sample the subtidal zone only. This would improve the understanding of seasonal trends for this stratum.

Other Concerns

Research requirements for the existing time series are to incorporate sediment characteristics (grain size, organic content) into the species diversity data in order to test assumptions regarding evenness of habitat type within strata, season, and year and to evaluate correlates between sediment characteristics and diversity to understand ecosystem function and potential other metrics as proxies to changes in species diversity.

FISHES

Authors: S. Courtenay, E. Ipsen, and D. Methven

Estuaries are recognized as regions of high productivity that support large densities of fish biomass. Due to resource requirements throughout their life history, small (generally < 30 cm) demersal and pelagic fishes that occur in the nearshore shallows of the Musquash MPA are constantly migrating into and out of the nearshore area, which results in a dynamic community that changes in terms of composition and structure throughout the year.

Available Dataset

Metrics collected include the number of each fish species caught in addition to standard lengths of each fish caught. Sampling for this work occurred in support of a Masters thesis (Ipsen 2013). The main goal of the thesis is to describe temporal and spatial trends of the nearshore fish community within the Musquash MPA and its surroundings. The objectives were to compare year-long nearshore fish communities in three different habitats within zone 2 of the MPA (studies 1 and 2) and to determine whether the fish community of the Musquash estuary differed from neighbouring estuaries (Dipper Harbour and Saints Rest Marsh) that do not benefit from the MPA designation (Study 3). Following the completion of the thesis, data collection stopped and is not on-going. A summary of collected data for each study is provided in Table 5.

Table 5. Sampling outline for studies 1-3 for the beach seine (studies 1.1, 2.1, 3.1) and fyke net (studies 1.2, 2.2, 3.2) at Black Beach (BB), Five Fathom Hole (FFH), Hepburn's Basin (HB), Saints Rest Marsh (SR), and Dipper Harbour (DH). N is the number of observations used in univariate and multivariate analysis for comparisons among sites and across seasons, unless otherwise specified. From Ipsen (2013).

Study	Sampling Gear	Sites Compared (N)			Dates From	Dates To	Sampling Frequency	Duration (months)
		BB	FFH					
1	1.1 Beach seine	23	23		Oct 2009	Oct 2010	Twice a month	11.5
	1.2 Fyke net	14	14		June 2010	Dec 2010	Twice a month	7
		BB	FFH	HB				
2	2.1 Beach seine	12	12	12	May 2010	Oct 2010	Twice a month	6
	2.2 Fyke net	10	10	10	June 2010	Oct 2010	Twice a month	5
		BB	SR	DH				
3	3.1 Beach seine	5	5	5	June 2010	Oct 2010	Once a month	5
	3.2 Fyke net	5	5	5	June 2010	Oct 2010	Once a month	5

Data Collection

Sampling protocols are standardized and are available in Ipsen (2013). Briefly, beach seine and fyke nets were used to collect fish at three sites within the Musquash MPA (Five Fathom Hole, Hepburn Basin and Black Beach), and at two sites adjacent to the MPA (Dipper Harbour and Saints Rest Marsh). Beach seine and fyke net sampling gear were chosen because they are non- destructive and do not damage the habitat or result in high mortality of fish. There is, however, some fish mortality associated with the use of fyke nets due to green crabs, which can kill or damage fish in a confined space. Due to variability, changes to the sampling protocol may be necessary if future sample is completed for monitoring purposes.

Recommended Analysis

Both univariate and multivariate analyses were used to explore the data. Data analyses include comparisons of species richness and catch per unit effort (CPUE) among the three sites within the MPA (Five Fathom Hole, Hepburn Basin, Black Beach) and comparison of Black Beach with two sites outside the MPA (Dipper Harbour, Saints Rest Marsh). A multivariate analysis comparing sites and across seasons (winter, spring, summer, autumn) was also completed, the details of which are provided in Ipsen (2013).

Features of Existing Time Series

For a detailed analysis of results, refer to Ipsen (2013). A summary of fish species collected throughout the study are summarized in tables 6 and 7. It was noted that a small number of species accounted for the majority of fish collected. Silverside, a small pelagic fish, dominated the beach seine catches. In comparison to beach seines, fyke nets collect fewer species and smaller catches but caught larger fish. Species richness and CPUE were highest during summer.

The beach seined fish community was significantly different between Black Beach and Five Fathom Hole ($p=0.004$) and among seasons ($p=0.001$), with there being no significant interaction term. Sites showed a weak separation in multidimensional scaling (MDS) analysis. All season pairwise comparisons, except for autumn and summer, had significantly different fish communities ($p<0.001$).

Community analysis among Hepburn's Basin, Black Beach and Five Fathom Hole from May 2010 to October 2010 indicated significant site (p=0.047) and season differences (p=0.001) with no significant interaction term. MDS analysis showed overlap among the three sites; however, distinct separation of seasons was evident. No significant site differences were detected; however, percent dissimilarity in community composition and abundance was highest between Black Beach and Hepburn's Basin.

When multivariate comparisons were made among beach seine catches of fish at Black Beach (inside the MPA) with Dipper Harbour and Saints Rest Marsh (both outside the MPA), the MPA fish (Black Beach) were not significantly different from fish collected at either site outside the MPA. However, the two most distant sites, both located outside the MPA (Dipper Harbour, Saints Rest Marsh), did have significantly different fish communities, which suggest a gradient of fish community change generally from the mouth of the Bay of Fundy towards the inner parts of the Bay.

Table 6. Summary of study one beach seine catches (top) and fyke net catches (bottom) for Black Beach and Five Fathom Hole). N is the total number of individual species caught for the duration of the study; Rank indicates species rank based on abundance; and % represents the percent contribution to the total number of individuals caught at a specific site. Bolded species were analyzed for site and season trends. From Ipsen (2013).

		Black Beach			Five Fathom Hole		
Gear	Species	N	Rank	%	N	Rank	%
Beach Seine	**Atlantic Silverside**	1567	1	84.75	581	1	44.62
	Winter Flounder	83	2	4.49	85	6	6.53
	Atlantic Smelt	63	3	3.41	71	7	5.45
	Blackspotted Stickleback	28	4	1.51	196	2	15.05
	Pollock	25	5	1.35	105	4	8.06
	Shorthorn Sculpin	21	6	1.14	90	5	6.91
	Atlantic Tomcod	19	7	1.03	47	8	3.61
	Threespine Stickleback	13	8	0.7	112	3	8.6
	Atlantic Herring	13	9	0.7	1	11	0.08
	Ninespine Stickleback	9	10	0.49	6	9	0.46
	Alewife	7	11	0.38	5	10	0.38
	Lumpfish	1	12	0.05	0	n/a	0
	Mummichog	0	n/a	0	1	11	0.08
	Sea Raven	0	n/a	0	1	11	0.08
	Rock Gunnel	0	n/a	0	1	11	0.08
	Total Individuals	1849	n/a	n/a	1302	n/a	n/a
Fyke Net	**Atlantic Smelt**	54	1	52.43	44	2	9.82
	Atlantic tomcod	25	2	24.27	380	1	86.76
	Pollock	15	3	14.56	2	5	0.46
	Winter Flounder	4	4	3.88	1	6	0.23
	Alewife	1	5	0.97	5	4	1.14
	American Eel	0	n/a	0	6	3	1.37
	Atlantic Cod	1	5	0.97	0	n/a	0
	Total Individuals	100	n/a	n/a	438	n/a	n/a

Note: Cells marked with a n/a indicates no applicable data.

Table 7. Summary of study two beach seine catches (top) and fyke net catches (bottom) for Black Beach, Five Fathom Hole and Hepburn's Basin. N is the total number of individuals caught for each species; Rank indicates species rank based on abundance; and % represents the percent contribution to the total number of individuals caught at a specific site. Bolded species were analyzed for site and season trends. From Ipsen (2013).

		Black Beach			Five Fathom Hole			Hepburn's Basin		
Gear	Species	N	Rank	%	N	Rank	%	N	Rank	%
Beach Seine	**Atlantic Silverside**	1380	1	88.18	485	1	43.81	1348	1	45.59
	Winter Flounder	45	2	2.88	59	7	5.33	112	5	3.79
	Atlantic Smelt	37	3	2.36	69	6	6.23	339	4	11.46
	Blackspotted Stickleback	26	4	1.66	194	2	17.52	649	2	21.95
	Pollock	25	5	1.6	105	3	9.49	1	11	0.03
	Shorthorn Sculpin	20	6	1.28	78	4	7.05	4	10	0.14
	Atlantic Tomcod	18	7	1.15	44	8	3.97	19	6	0.64
	Alewife	7	8	0.45	0	n/a	n/a	1	11	0.03
	Atlantic Herring	6	9	0.38	0	n/a	n/a	0	n/a	0
	Ninespine Stickleback	0	n/a	0	0	n/a	n/a	1	11	0.03
	Threespine Stickleback	0	n/a	0	70	5	6.32	449	3	15.18
	Mummichog	0	n/a	0	1	9	0.09	9	8	0.3
	White Hake	0	n/a	0	0	n/a	0	16	7	0.54
	Smooth Flounder	0	n/a	0	0	n/a	0	9	8	0.3
	Rock Gunnel	0	n/a	0	1	9	0.09	0	n/a	0
	Sea Raven	0	n/a	0	1	9	0.09	0	n/a	0
	Lumpfish	1	10	0.06	0	n/a	0	0	n/a	0
	Total Individuals	1565	n/a	n/a	1107	n/a	n/a	2957	n/a	n/a
Fyke Net	**Atlantic Smelt**	36	1	50.00	10	2	2.72	5	2	2.81
	Atlantic Tomcod	20	2	27.78	345	1	93.75	155	1	90.45
	Pollock	13	3	18.06	0	n/a	0	5	2	2.81
	Winter Flounder	2	4	2.78	1	6	0.27	3	4	1.69
	White Hake	0	n/a	0	0	n/a	0	3	4	1.69
	American Eel	0	n/a	0	6	3	1.63	0	n/a	0
	Alewife	0	n/a	0	5	4	1.36	1	6	0.56
	Atlantic Silverside	1	5	1.39	0	n/a	0	0	n/a	0
	Threespine Stickleback	0	n/a	0	1	6	0.27	0	n/a	0
	Total Individuals	72	n/a	n/a	368	n/a	n/a	178	n/a	n/a

Note: Cells marked with n/a indicate no applicable data.

Baseline Values

No baseline values were calculated. However, it is possible to calculate baseline values for the time of year that future sampling would be completed (likely summer – when catches and richness were highest) as well as some measure of variation. If calculated, this (these) baseline value(s) would be based on one year of data, i.e., one summer of data. The baseline value(s) would be comparable given that sampling methods, site and time of year remain unchanged. The only variable that would change is year.

Reference Points

Ideally, to encompass natural annual variability, additional years (summers) of data would be necessary to develop reference points. As there is only one year of sampling data available, i.e., one summer of data available, no reference points have been calculated.

BIRDS

Author: K. Allard

Musquash is an important area for marine birds throughout the year. Information on marine birds is currently being gathered by biologists and community volunteers through Bird Studies Canada and Environment Canada's Canadian Wildlife Service. Existing federally (Table 8) and non-federally (Table 9) funded bird monitoring programs in the southwest New Brunswick portions of the Bay of Fundy include the Atlantic Coastal Waterfowl Survey, Eastern Waterfowl Survey, Eider Winter Survey, Atlantic Canada Shorebird Survey, Purple Sandpiper Survey, Eastern Canada Seabirds at Sea survey, Atlantic Region Colony Survey, Maritimes Marsh Monitoring Program, and the Maritimes Breeding Bird Atlas. Formal analyses to specifically establish potential contribution to MPA monitoring have not been undertaken for any of these datasets. Additional information on data collection methods are outlined in Appendix 2.

Table 8. Summary of federally funded bird monitoring programs in the southwest New Brunswick portions of the Bay of Fundy.

Survey	Time Series	Priority Species
Atlantic Coastal Waterfowl Survey	Annual: 1960-2010	American Black Duck, Mallard, Common Goldeneye, Common Loon, American Green-winged Teal, Common Eider
Eastern Waterfowl Survey	2005-2006	American Black Duck, Mallard, Common Goldeneye, American Green-winged Teal
Eider Winter	Triannual: 2003-2012, on-going	Common Eider
Atlantic Canada Shorebird Survey	1974-on-going	Hudsonian Godwit, Black-bellied Plover, Lesser Yellowlegs, Sanderling, Red Knot, Semipalmated Sandpiper, Dunlin, Least Sandpiper, Whimbrel, Spotted Sandpiper, Willet, American Golden Plover, Killdeer
Purple Sandpiper Survey	2007, on-going	Purple Sandpiper
Programme intégré des recherches sur les oiseaux pélagiques	1966-1992	Common Tern, Arctic Tern, Bonaparte's Gull, Common Murre, Leach's Storm-Petrel, Razorbill, Red-necked Phalarope, Roseate Tern, etc.
Eastern Canada Seabirds at Sea	2006, on-going	Common Tern, Arctic Tern, Bonaparte's Gull, Common Murre, Leach's Storm-Petrel, Razorbill, Red-necked Phalarope, Roseate Tern, etc.
Atlantic Region Colony Database	1960, on-going	Herring Gull, Great Black-Backed Gull, etc.

Table 9. Summary of non-federally funded bird monitoring programs in the southwest New Brunswick portions of the Bay of Fundy.

Survey	Time Series	Priority Species
Maritimes Marsh Monitoring Program	2012-2013	American Bittern, Least Bittern, Sora, Virginia Rail, Yellow Rail, American Coot, Common Moorhen, Nelson's Sparrow, Pied Billed Grebe
Maritime Breeding Bird Atlas	20 yr frequency: 1986-1990 and 2006-2010	250+ bird species breeding in the Maritimes

HUMAN PRESSURES

Authors: P. Doherty, T. Koropatnick, and M. Abbott

It is recognized that certain activities in the MPA may affect the natural environment but may still be allowed to occur provided they abide by other applicable legislation, regulation and policies. Pursuant to the Musquash Estuary MPA regulations, a range of human activities are excluded, permitted, or may require approval prior to being undertaken in the protected area. Human activities exempted from the general prohibitions include, but are not limited to, Aboriginal, commercial, and recreational fishing.

COMMERCIAL AND RECREATIONAL LANDINGS

Fisheries allowed in the MPA as per the Musquash Estuary MPA regulation include:

1. fishing that is carried out in accordance with the *Aboriginal Communal Fishing Licences Regulations*,
2. recreational fishing activities carried out in accordance with the *Atlantic Fishery Regulations, 1985* or the *Maritime Provinces Fishery Regulations*, namely,
    a. manually fishing for scallops or clams, and
    b. fishing for any other species by means of angling or a dip net;
3. commercial fishing activities carried out in accordance with the *Atlantic Fishery Regulations, 1985* or the *Maritime Provinces Fishery Regulations*, namely,
    a. in Zone 1, fishing for elvers or eels by means of a hand-deployed fyke net or dip net,
    b. in Zone 2A, 2B or 3, fishing for lobster by means of individual traps and for herring by means of a weir, beach seine, bar seine or drag seine,
    c. in Zone 3, fishing for scallops, and
    d. in any Zone, manually fishing for clams;
4. in Zone 2A, 2B or 3, the recreational or commercial harvesting of dulse manually.

Available Dataset

In general, commercial fisheries participants (including Aboriginal) are required by licence to submit data on fishing activity to DFO using fishery-specific monitoring documents (logbooks). Commercial fisheries data captured in fishing logbooks are stored in the Maritimes Fishery Information System (MARFIS), a regional repository for licensing, vessel, participant (fisher), quota, and catch (species caught, estimated weights, catch date, location) and effort (hours or days fished, amount of gear) information. Within the Musquash MPA, only the scallop fishery is currently required to report geographic information about catches at a resolution that is useful for MPA monitoring. For this analysis, catch and effort data for the scallop fishery was acquired from MARFIS for a six year period (January 2007 to December 2012). Data are available prior to MPA designation as well and could be used to compare usage pre- and post-designation.

Data for elvers, eels, clams and dulse are not available in MARFIS. The MPA has been closed to clam harvesting in recent years due to bacterial contamination. In MARFIS, lobster data is reported by 10 x 10-minute statistical grid (DFO 2007). This grid is too large for monitoring the portion of the lobster fishery that occurs in the MPA

Data Collection and Recommended Analysis

For the scallop fishery, MARFIS data for 2007–2012 were acquired using DFO's Virtual Data Centre (VDC) and plotted within a study area encompassing the fishable portion of the Musquash MPA (Figure 29). The total catch weights both within and outside the MPA were

summed for each year of the assessment period and fishing patterns and trends were examined (data could not be provided to protect confidentiality). While the analysis focused on the scallop fishery, a single entry for a sea urchin catch was also reported within the MPA boundaries during the study period. This entry may be erroneous or may indicate unlawful fishing activity in the area, as fishing for sea urchin is not allowed under Musquash MPA regulations.

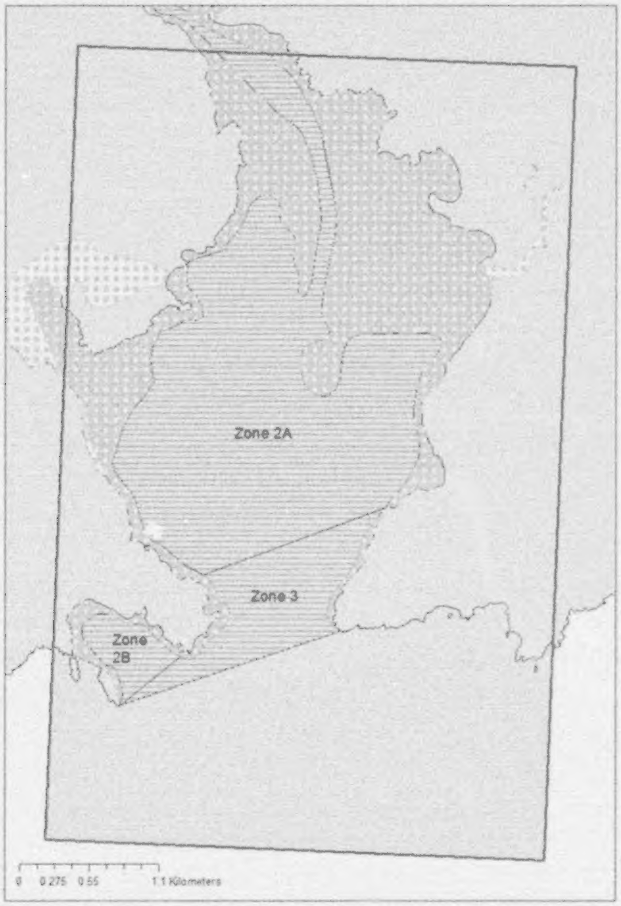


Figure 29. Scallop data from 2007–2012 were analyzed within an assessment area (blue polygon) encompassing the fishable portion of the MPA (striped blue area) and within an area (solid blue) adjacent to the outer boundary (stippled grey line). Brown with white stippling: Administered Intertidal Area; white with brown stippling: intertidal area.

For fisheries that occur in the study area with reporting requirements that are not adequate for monitoring at the scale of the MPA (i.e., lobster, elvers, eels, herring, and dulse), a Local Use Study may be done to determine fishing effort in the area. This can be done using semi-structured interviews with subject matter experts (e.g., Conservation and Protection Branch staff and local fishers) to determine locations and intensity of fishing activities (Wagner 2011, and Squires and Gromack, unpublished manuscript, for methodology[2]). Paper maps used to gather

[2] Unpublished report "Extent and importance of commercial fishing activity in the vicinity of St. Anns Bank AOI, as described by selected traditional sources" produced for the Oceans and Coastal Management Division, DFO, Maritimes Region, Dartmouth, Nova Scotia, by K. Squires and A. Gromack (2013).

data during the interviews would be digitized in ArcGIS and results analysed by species, gear types and location. A Local Use Study is recommended every five years.

No data has been collected to date to characterize pressures presented by fisheries for lobster, elvers, eels, herring, or dulse.

Baseline Values

No baseline value for this indicator is suggested. Rather it is recommended that these data be analyzed annually (for fisheries with available MARFIS data) or every five years (for fisheries information gathered by Local Use Study) to help explain any changes in the ecosystem that are noted by other indicators.

Reference Points

There are no reference points for this indicator.

Other Relevant Concerns

As it currently stands, the limited available fisheries data necessitates the implementation of regular Local Use Studies to help characterize and monitor fishing related pressures on the Musquash ecosystem. These projects can be expensive and time consuming, and they are not practical for on-going MPA monitoring purposes. Currently in the Musquash MPA, scallop is the only commercial fishery that is required to report geographic locations of catches at a resolution that is adequate for MPA monitoring. Similar requirements could be investigated for other commercial fisheries active in the MPA (e.g., the lobster fishery) so that these pressures can be adequately and efficiently monitored.

BY-CATCH NUMBER, SIZE, AGE, AND SEX PER IMPACTED SPECIES

These indicators would be determined through baseline measurement and review of historical fishery records, if available. Data must be at an appropriate resolution to assess landings in and adjacent to the Musquash Estuary.

Available Dataset

The At-Sea Observer program places fisheries observers on fishing vessels to monitoring fishing practices and provide detailed information on catch composition (including estimated weights of kept species and discards). While this program can provide a wealth of data to help characterize fishing pressures, coverage can be limited. For fisheries in the vicinity of Musquash MPA, only the scallop fleet participates in the program, and no trips to the MPA have included an observer based on available data in the At-Sea Observer database.

Alternative sources of data could include data collected as part of a local ecological knowledge study.

Given the gear used for the elver, eel, clam and dulse fisheries, by-catch is not likely an issue of concern and therefore will not be assessed further.

Data Collection and Analysis

Available data in the At-Sea Observer database would be accessed through the VDC, and catch weights within and adjacent to the MPA would be summed for each by-catch species for each year of the study period (note that information on sex, age, size, and number of individuals per species is not recorded by observers, so data from this source would be limited to estimated catch weights per species). Consideration should be given to requiring observer coverage for fisheries in the MPA (e.g., two targeted observer coverage trips per year for the scallop fishery).

Alternatively, a Local Use Study could be conducted to characterize relative by-catch levels by species for fisheries active in the area. This can be done using semi-structured interviews with

subject matter experts (e.g., Conservation and Protection Branch staff and local fishers) to determine locations and intensity of fishing activities (Wagner 2011, and Squires and Gromack, unpublished manuscript, for methodology[3]). While it is likely that only general information related to by-catch species will result from the interviews, if such a study were conducted at five year intervals, trends in by-catch profiles may become apparent over time.

Features of Existing Time Series

Collected data have not been analysed to characterize by-catch number, size, age or sex of impacted species.

Baseline Values

No baseline value for this indicator is suggested. Rather, it is recommended that these data be analyzed annually (for fisheries with available Observer Program data) or every five years (for fisheries information gathered by Local Use Study) to help explain any changes in the ecosystem that are noted by other indicators.

Reference Points

There are no reference points for this indicator.

Research Requirement in Support of Monitoring

Consideration could also be given to engaging local lobster fishermen to participate in by-catch studies to help gather appropriate data (e.g., through Fishermen and Scientists Research Society).

DEGREE OF HUMAN INDUCED HABITAT PERTURBATION OR LOSS

Available Dataset

The marine debris (specifically from illegal dumping and littering, some of which is discarded on the beach and some of which floats in) dataset has been collected since (at least) 2008 from Black Beach (proper, upland and top of the hill) and Gooseberry Cove Beach. Digital copies are available in standardized format since 2009. In 2009, a monthly cleanup was completed in July, August, and September. In 2010 and 2011, monthly cleanups were completed in July, August, and October. In 2012, monthly cleanups were done in June-September (inclusive) and November. At the time of writing in June 2013, monthly cleanups had been conducted in March and June, and more were planned for August to November.

Activities for which an application is required to be submitted to DFO and approved prior to commencement (i.e., scientific, educational, archaeological, commercial tourism, habitat restoration activities) in the MPA have been tracked since 2007. All of these activities were evaluated to have a negligible to low impact on habitat in the MPA.

While there are available datasets of aerial photographs, orthophotomaps, and high resolution satellite imagery of the Musquash area (Byrne 2001; Service New Brunswick 2010[3]), no analysis of the shoreline has been conducted. It may be difficult to distinguish human-induced perturbation or habitat loss from those caused by natural processes using these data.

Data Collection and Analysis

Debris is collected, recorded by item on a Standard Shoreline Cleanup form, and entered into an Microsoft Office Excel© spreadsheet that is categorized into plastic, polystyrene, glass, metal, rubber, paper, wood, miscellaneous debris, and individual items. It is recommended that

[3] To view satellite imagery for Musquash, visit the CanMaps website for the Musquash satellite image map at http://www.canmaps.com/topo/nts50/orthoimage/021g01.htm.

marine debris monitoring be completed five to six times per summer (monthly from June to November) on Black Beach and Gooseberry Cove Beach. Specific recommendations are not provided for analyzing data.

As per the Musquash Estuary MPA Regulations, applications for activities in the MPA are to be submitted to DFO at least 60 days prior to the commencement of the proposed activity. DFO then has 30 days to respond to the proponent. Activities are evaluated and ranked (negligible, low, medium, high) based on anticipated environmental effects on species and habitats, as well as overall impact to the MPA. Recommendation to consider evaluation of environmental effects of proposed activities on habitat, productivity and biodiversity, to better align with MPA conservation objectives. Improved tracking/monitoring of shoreline activities approved through the activity application process is recommended (e.g., before and after photographs as a condition of approval).

It is recommended, that as part of the activity evaluation process, the analysis of the proposed activity's environmental effects should include consideration for impacts on habitat, productivity, and biodiversity within the MPA, thus ensuring alignment with the MPA's conservation objectives. Improved tracking/monitoring of shoreline activities approved through the activity application process (e.g., before and after photographs as a condition of approval) is also recommended.

It is recommended that a regular survey of shoreline areas that may be vulnerable to human use (e.g., access points to the MPA, sensitive habitats) be undertaken for baseline monitoring and then monitored over time. These areas must first be identified and then the appropriate form of data collection (e.g., ground or aerial photos) should be determined. Three to five year surveys are recommended.

Baseline Values

No baseline value for the marine debris or activity plan application indicators is suggested. Rather, it is recommended that shoreline cleanup data be analyzed annually and shoreline survey data be analyzed at three to five year intervals to help explain any changes in the ecosystem that are noted by other indicators.

MUSQUASH COMMUNITY COMPOSITION

Author: M. Greenlaw

The Musquash MPA may have similar community composition patterns to other areas in the Bay of Fundy/Scotian Shelf based on meso-scale physiographic features and smaller scale macro-habitat distribution patterns. These areas were identified based on a deductive approach to classifying benthic communities, from analysis of the physical environment (physical habitat mapping). Physical variables have been shown to account for a proportion (20-75%) of variability in community composition patterns, depending on the species and system. The remaining variability is expected to come from unmeasured variables, variables at different scales, biological relationships (competition and predation), and human pressures.

In the coastal portion of the Scotian Shelf/Bay of Fundy, temperature, salinity, depth, chlorophyll, and geomorphology are expected to be the most important variables at a meso-scale. These factors have been used to create meso-scale physiographic units for the coastal zone (Figure 30). The Bay of Fundy has been separated into three physiographic units, the inner Bay of Fundy, the Quoddy Region, and Grand Manan banks and basins, which have been further separated into sub-units based on oceanographic and geomorphological variables, but at a smaller scale (Figure 31). Within these physiographic units, a variety of geomorphic features (inlets, banks, basins and plains) and depth zones (0-50, 50-110, 100-200, 200-300), which are also related to community composition patterns (Figure 32), are evident.

Musquash Estuary is characterized as an inlet within the 0-50 m depth zone (Figure 32) of the Quoddy physiographic region, sub-unit 3 (figures 30 and 31). Within inlets, different communities (Archambault et al. 1999; Archambault and Bourget 1999) are expected, as indented shorelines have the ability to trap inert particles. Within estuarine inlets, organisms must tolerate physiologically demanding conditions of lowered salinity and high proportions of shelter, which also influence oxygen concentrations and turbidity levels. While few species are able to tolerate these environments, those that can are typically present in higher abundances. At a finer scale, communities are highly responsive to primary habitat patterns including substrate (figures 33 and 34), exposure, salinity and temperature, which create gradients, based on these factors, within the inlet. It is anticipated that communities present in Musquash are most similar to other estuarine inlets within the same physiographic unit (Quoddy 3; Figure 31). The most closely related inlets are expected to be Maces Bay and Saint John Harbour due to substrate, temperature, shelter and freshwater input patterns.

Figure 30. Coastal meso-scale physiographic units in/on the Scotian Shelf/Bay of Fundy defined using oceanographic and geomorphological variables (Greenlaw et al., unpublished report)[4].

Community composition patterns similar to those within the Musquash MPA are expected in subtidal muddy habitats, intertidal sand flats, and marshes within inlets in the Quoddy Region 3, especially within inlets with similar salinity/temp/turbidity regimes to Musquash inlet. A degree of overlap between subtidal muddy habitats in Musquash and subtidal muddy habitats in the 0-50 m bathome (outside inlets) in the Quoddy 3 physiographic region are expected. Moreover, a lesser degree of overlap between subtidal muddy habitats, intertidal sand flats, and marsh areas in other close physiographic units (inner Bay of Fundy, Grand Manan banks and basins, and possibly western Nova Scotia) are expected.

[4] Unpublished report "A subtidal ecological classification system to represent species diversity and distribution patterns in the Maritimes Region" by by M.E. Greenlaw (2013).

While Musquash does not appear to have unique habitat types, the proportion of these habitat types is unique, as Musquash may have a higher proportion of marsh and intertidal sand flat than other inlets within the Quoddy Region. This also suggests that Musquash would not likely house any unique or rare species.

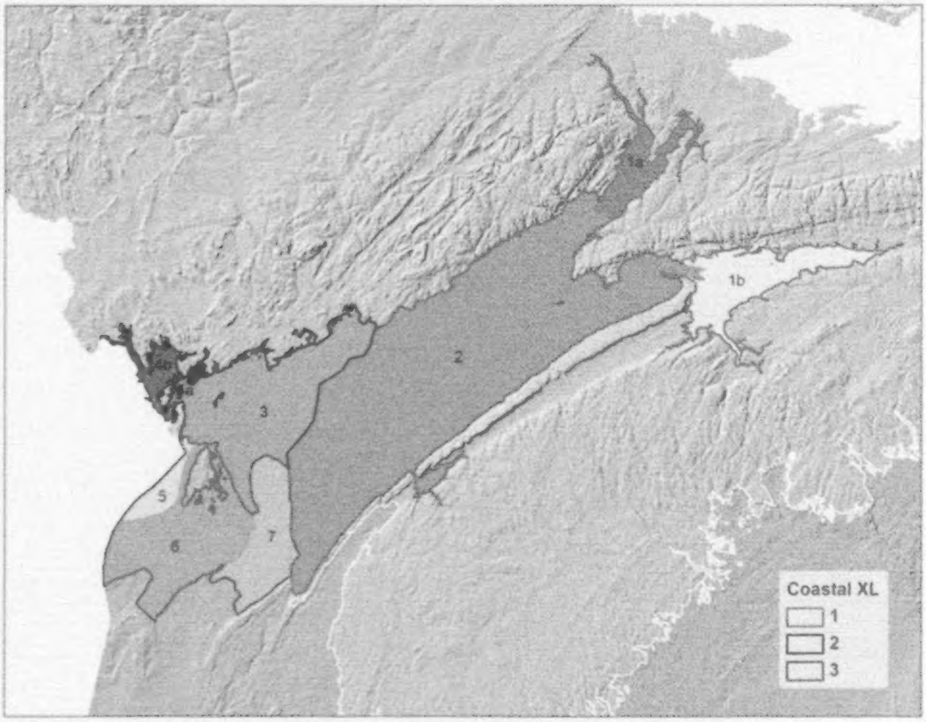


Figure 31. Coastal meso-scale physiographic sub-units in the Bay of Fundy.

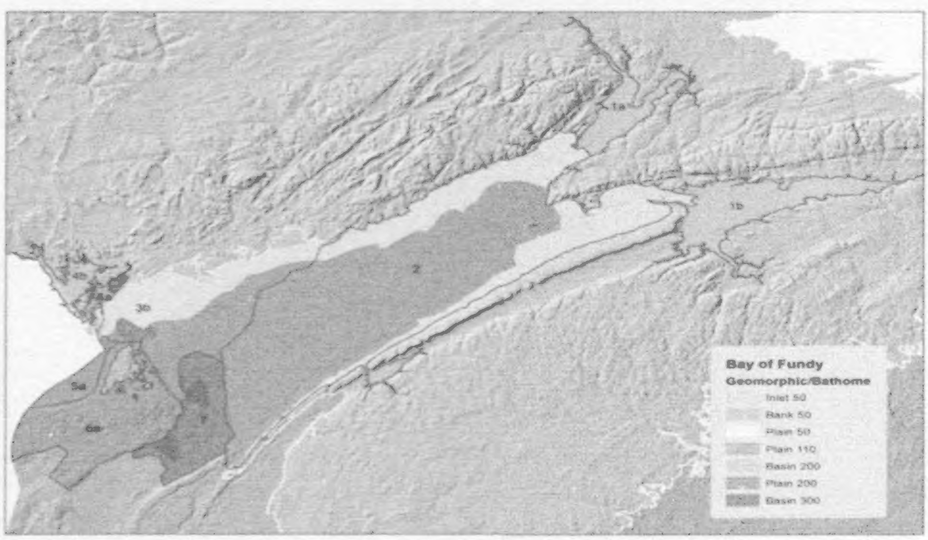


Figure 32. Distrubtion of bathomes and geomorphic features within coastal physiographic sub-units in the Bay of Fundy.

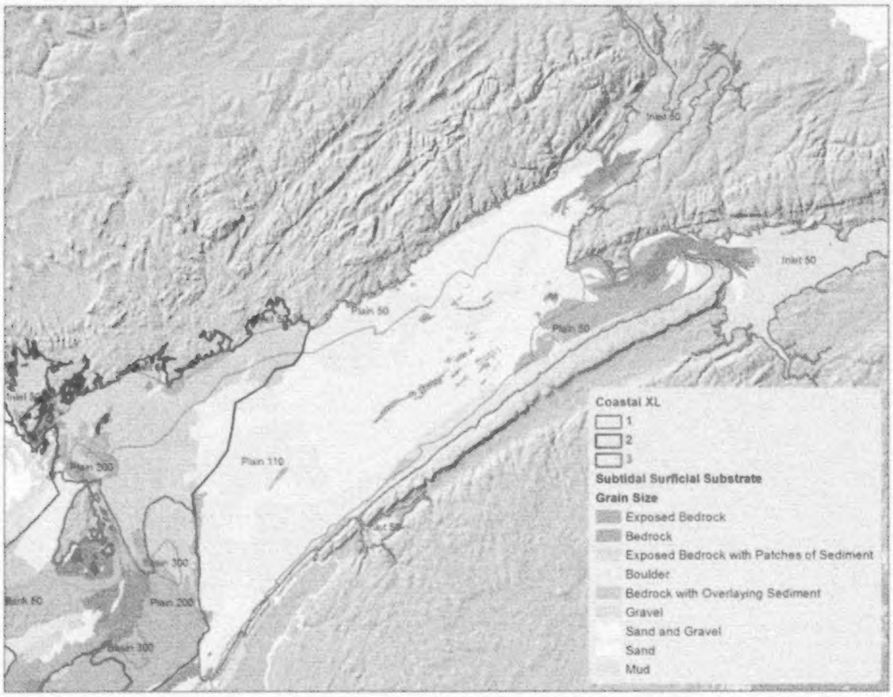


Figure 33. A habitat classification indicating macro-scale habitat features within meso-scale physiographic units.

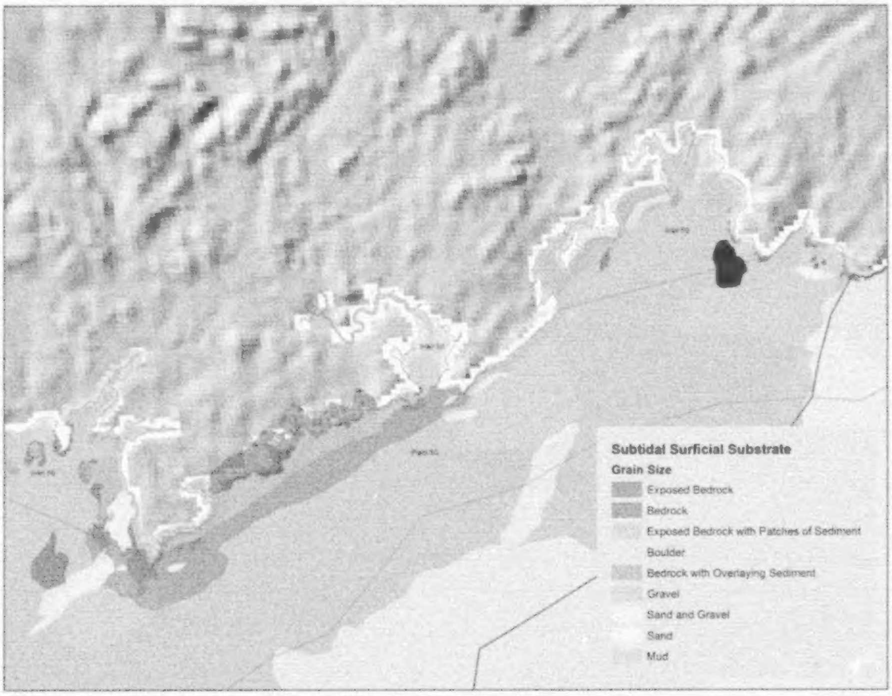


Figure 34. The distribution of macro-scale habitat features within the meso-scale physiographic regions of the surrounding area to Musquash inlet.

DISCUSSION AND CONCLUSIONS

In support of the Health of the Oceans Initiative, DFO Science is to deliver indicators, strategies, and protocols for monitoring the individual conservation objectives of MPAs that have been established pursuant to the *Oceans Act*. In deciding upon appropriate indicators, consideration must be given to their relevance to the conservation objectives, cost, and feasibility of implementation. Further, a successful indicator is supported by baseline data, can be linked both to the ecosystem and human activities, and permit a differentiation between spatial and temporal natural variation and human induced changes to the ecosystem over the long term.

Improving the understanding of the structure and functioning of the Musquash Estuary ecosystem is essential to establishing meaningful baseline values. Research and monitoring activities pertaining to benthic diversity, physical oceanography, sedimentation rates and metal history, fish community assemblages, bird population surveys, and human threats have been and continue to be undertaken in the Musquash Estuary. The available benthic biodiversity data suggest that current sampling efforts are sufficient to establish baseline vales for species richness, species diversity within the different strata, and dominant taxa. Furthermore, correlation analysis with other biological, physical, and chemical parameters would help in understanding the function of the benthic ecosystems. Sedimentation rates for estuary have been estimated. Data analysis indicates that the existing metals inventory cans be used as a baseline for future monitoring. It is recommended that a complete grain size survey be completed as this baseline data would allow for a surficial map to be created. Phytoplankton data from the long term time series represent a reliable baseline dataset for the Bay of Fundy. Although few samples have been collected from Musquash, results from the regular long term phytoplankton dataset in the southwestern New Brunswick portion of the Bay of Fundy could be applied to give an estimate of populations and species composition and abundance for Musquash. If additional coverage is thought to be beneficial, an additional sampling could be added at Musquash on an occasional basis for comparison with the regularly monitored sites. The results of fish sampling within the Estuary provide a good representation of the fish assemblages at each of the three sites; however, all of the sampling was conducted in shallow water at low tide (an important source of variation). If future sampling was were done for comparison with baseline data, additional tows per sampling trip would enhance the quality of the data and reduce the variability associated with species richness and with catches.

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APPENDICES

APPENDIX 1

Table A1. Linkages between conservation objectives and proposed indicators, reference points, monitoring strategies, and monitoring frequencies. An alpha-numeric designation has been assigned for each indicator based on its conservation objective (P–productivity, B–biodiversity, H–habitat). The designations are used to link monitoring strategies and protocols with the general objectives and indicators that are listed in this table.

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
Productivity so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species	Total biomass and spatial distribution of species in each trophic level within each ecotype **(P1)**	To be determined through baseline measurement	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats	To be determined
	Abundance of juvenile fish within the estuary **(P2)**	To be determined through baseline measurement	Survey of juvenile fish species in the estuary using beach seines and/or fyke nets	To be determined
	Phytoplankton concentration within the estuary **(P3)**	To be determined through baseline measurement	Survey of phytoplankton concentration within the estuary, including chlorophyll-a	To be determined
	Commercial and recreational fishery landings **(P4)**	To be determined through baseline measurement	Survey of landings by fishery and species that occur in and adjacent to the MPA, if available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary)	Annual review
Biodiversity by maintaining the diversity of individual species, communities, and populations within the different ecotypes	Number of species in each trophic level within each ecotype, and the abundance of keystone and/or dominant species **(B1)**	To be determined through baseline measurement	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable)	To be determined
	Number of exotic species within each ecotype, relative to exotic species in region **(B2)**	To be determined through baseline measurement	Survey of exotic species within each ecotype, and estimate of exotic species in region through standardized per area sampling such as transect or quadrats (visual surveys where applicable)	To be determined
	Number of species at risk within each ecotype **(B3)**	To be determined through baseline measurement	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable)	To be determined
	By-catch number, size, age, and sex per impacted species **(B4)**	To be determined through baseline measurement and review of historical fishery records, if	Survey of by-catch number, size, age, and sex of captured individuals per fishery	Annual review

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
		available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary)		
Habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality	Total area and location of each ecotype within the estuary, and the proportion and frequency that it is disturbed or lost **(H1)**	To be determined through baseline measurement	Map area distribution of each ecotype within the estuary using aerial photographs and GIS software	To be determined
	Total area and location within estuary of species that provide biogenic structure (e.g., marsh and rockweed) **(H2)**	To be determined through baseline measurement	Map area distribution that supports species that provide biogenic structure	To be determined
	Hydrodynamic and sediment regime within the estuary (e.g., sediment infilling) **(H3)**	To be determined through baseline measurement.	Field sampling coupled with hydrodynamic and sediment models that predict the deposition/erosion of sediment, as well as the hydrodynamic regime	To be determined
	Degree of human induced habitat perturbation or loss **(H4)**	To be determined through baseline measurement	Survey of shoreline activities such as construction and dumping	To be determined
	Temperature and salinity within the estuary **(H5)**	To be determined through baseline measurement and records from NB Power	Survey of temperature and salinity within estuary	To be determined
	Nutrient concentrations within the estuary **(H6)**	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels	Survey of nutrient concentrations within estuary (dissolved oxygen, silicon, iron, carbon, nitrogen, and phosphorus)	To be determined
	Contaminant concentrations within the estuary **(H7)**	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels	Survey of contaminant concentrations within bottom sediment and water column (dissolved and particulate bound trace metals and organics)	To be determined

Note: *CCME – Canadian Council of Ministers of the Environment.

APPENDIX 2

Below are data collection protocols for various bird monitoring surveys completed by Environment Canada's Canadian Wildlife Service (EC CWS).

Atlantic Coastal Waterfowl Survey (ACWS: EC CWS Atlantic Region)

Data are derived from aerial surveys of waterfowl (e.g., ducks and geese) occurring within coastal and inshore waters of Atlantic Canada. Within this dataset, raw data are compiled within polygons rather than by points. The sampling unit for these databases is the "Coastal (and inshore) Waterfowl Block". Coastal waterfowl 'block polygons were established at the beginning of the monitoring program and have remained fixed over time. Polygon sizes differ geographically (within and among EC CWS Regions) and are irregularly shaped. 'Blocks' were initially designed to reflect prominent coastline features that separate coastal segments, inshore bays and estuaries, and, thus, define functionally distinct habitat units (for waterfowl). Records include counts of each waterfowl species observed within each polygon during each survey visit. Visits vary in annual timing depending on monitoring objectives. Records also include incidental observations of other coastal bird species.

It may not be possible for observers to all identify individuals or flocks of birds to species. As such, individuals can be assigned to genus, or subfamily. Relatively extensive quantities of incidental records (i.e., not gathered consistently) of other bird species, mostly marine water birds, can be found within this database. In particular, records include coastal and inshore zone species not well captured through other surveys (e.g., loons, grebes, gulls, shorebirds, herons and cormorants). Counts of Common Eider associated with breeding colonies (typically in May) and Wintering Black Duck (typically mid-January to early March) can be found within this dataset. Coastal Waterfowl surveys are on-going within EC CWS Atlantic Region.

Count data are vulnerable to multiple sources of variation. An unknown number of individuals can be missed during a survey visit due to survey timing, light conditions, weather conditions, flight track omissions, etc. Not all survey polygons are visited annually, though more systematic approaches to survey timing and coverage have been adopted.

Eastern Waterfowl Survey

Available data within Musquash were collected from surveys conducted from 2005-2006 to establish comparisons between a Ducks Unlimited site and control site at Red Head Marsh. These data were collected by CWS on behalf of Ducks Unlimited Canada; however, the data collection protocols of the Eastern Waterfowl Survey were followed.

The monitoring dataset is derived from aerial surveys of waterfowl within Atlantic Canada during the breeding season. Though these surveys capture many waterfowl species that can be found occupying coastal and inshore habitats, the focus is on breeding waterfowl within terrestrial rather than coastal breeding habitats. In contrast with summarized observations by 'coastal waterfowl block' polygon, geospatial information (i.e., with their respective latitudinal and longitudinal coordinates) is recorded for each individual observation to facilitate the calculation of breeding densities within one square kilometer survey squares. Zero counts can be derived from flight tracks. Incidental records (i.e., not gathered consistently) of other species also can be found within this database.

At present, no repeat surveys are planned for survey squares within the Musquash MPA.

Eider Winter

This aerial survey has been developed to monitor Common Eider, as its distribution and populations cannot be thoroughly assessed through other on-going waterfowl monitoring

programs (i.e., Atlantic Coastal Waterfowl Survey). This dataset focuses on the distribution and abundance of the Common Eider in Atlantic Canadian and Quebec inshore waters. The approach relies on the recording of spatial coordinates associated with individual birds and/or flocks. In addition, distance information is gathered for each observation, allowing the calculation of distance-corrected areal density estimates for each flight transect. As data records (i.e., counts) are associated with detections, records are not generated in the absence of detections (zeroes). As such, zero values must be derived from flight tracks. Almost all parts of Eastern Canada's Atlantic coast have been surveyed since the survey's inception. Pattern overlap across years may constitute evidence of persistent use.

Incidental records (i.e., not gathered consistently) of other marine bird species can also be found within this dataset. In particular, records of species not well captured by other surveys, or in coastal and inshore habitats, are available (e.g., loons, grebes, gulls, shorebirds, cormorants).

This survey assesses the use of exposed, rocky reef and shoreline habitat by the Common Eider in winter, including kelp, rockweed beds hosting bivalve and other mollusk, as well as echinoderm prey. Large flocks of Common Eider are expected to occur in the outer portions of the estuary; however, larger concentrations typically occur near Point Lepreau and in Maces Bay.

Atlantic Canada Shorebird Survey (ACSS)

This dataset began as the Maritimes Shorebird Survey (MSS), following initial efforts by CWS employees to monitor migrating shorebirds at a limited number of sites. The program now enlists skilled volunteer contributors from throughout Atlantic Canada. Repeated within-season surveys follow a defined protocol and typically occur during spring, summer and fall periods at established locations. This monitoring program captures information on relative distribution and abundance of migrating (staging) shorebird species occurring at exposed tidal flat locations.

Atlantic Canada Shorebird Survey sites are located to the east of the MPA, at Lorneville, Manawagonish Marsh, and Saints Rest Beach and Marsh.

The latter is a long term ACSS monitoring site. Shorebird records from within Musquash MPA are limited.

Purple Sandpiper Survey

This survey focuses on a shorebird species not adequately captured within the ACSS as Purple Sandpiper only occur in winter in Atlantic Canada and inhabits rocky coastal as opposed to tidal flat sites. Since 2007-2008, efforts have been made to survey rocky shoreline habitat to identify Purple Sandpiper overwintering sites. Point data generated from site-specific surveys contain information on counts and species observed.

This survey assesses the use of exposed, rocky reef and shoreline habitat by Purple Sandpiper. This habitat includes exposed kelp, rockweed beds and rocky substrate hosting small invertebrate prey. Large flocks are typically associated with sites within the outer estuary. Records of this species exist for Maces Bay, Dipper Harbour, and Point Lepreau to the west of the MPA, and Saints Rest Beach and March to the east. There are no records for the MPA within this dataset. Incidental records of this species, within the Coastal Waterfowl Block which encompass the MPA, can be found in the Coastal Waterfowl Database.

Programme intégré des recherches sur les oiseaux pélagiques (PIROP)

PIROP data were initially gathered through ship-based linear transects of unlimited width representing the total number of birds encountered per kilometer travelled (i.e., producing linear densities). Modifications in survey methods that occurred over the span of this program have

been accounted for in the raw data (Lock, pers. comm.). Final modifications to the protocol involved the establishment of a 300 m transect width (i.e., allowing calculation of both linear and areal densities). Since the bulk of the data were collected prior to the protocol update, areal densities cannot be calculated across the entire dataset, although efforts have been made and methods proposed to do so (Diamond et al. 1986; Gaston et al. 1987). Further, as distance information (i.e., lateral distance from the observer) associated with individual bird observations was not gathered, areal densities derived from those PIROP data gathered within the transect cannot be corrected using species detectability functions (i.e., DISTANCE software) to estimate 'true' areal densities.

Eastern Canada Seabirds at Sea

The Eastern Canada Seabirds at Sea program effectively constitutes the continuance of the PIROP program. However, ship-based surveys are based on an updated protocol, using fixed-width 300 m transects, divided into distance bands from which measures of areal bird density can be derived (i.e., number of birds per square kilometer). In addition, as each observation is associated with a specific distance band, raw areal density measures can be corrected to account for the varying detectability of different species as lateral distance from the observer increases. This strategy allows the calculation of more accurate estimates of 'true' areal densities.

Atlantic Region Colony Database

The Atlantic Region Colony Database contains records of individual colony counts, by species, for known colonies located in Atlantic Canada. Although some colonies are censused annually, most are visited less frequently. Methods used to derive colony population estimates vary markedly among colonies and species. For example, census methods devised for burrow-nesting alcids typically rely on ground survey techniques. As such, they tend to be restricted to relatively few colonies. In contrast, censuses of large gull or tern colonies, which are geographically widespread, rely on a combination of broad scale aerial surveys, and ground surveys at a subset of these colonies. In some instances, ground surveys of certain species are not available throughout the study area. In such cases, consideration of other sources, including aerial surveys, may be appropriate. It is important to note that though alternate sources of data may be available (e.g., Maritimes Breeding Bird Atlas, provincial sources), colony data for some species, such as herons, at present are not well represented in this database.

The database identified two colonies located within the Musquash MPA: Gooseberry Island (Herring Gull, Great Black-backed Gull) and Musquash Island (Herring Gull).

Maritimes Marsh Monitoring Program

This program is being piloted at coastal and non-coastal marsh locations throughout the Maritimes. Standardized survey protocols (Conway 2008) are implemented at 17 point locations in several habitat types, e.g., wet meadow, shallow marsh, deep marsh, coastal wetlands (i.e., tidal salt marsh) and forested wetlands, in the Musquash Estuary MPA. Additional bioacoustic monitoring using song meters was completed at a subsample of sites. Time and type of detection (auditory versus visual) data is collected for each individual of a primary focal species. Count data is collected for all other species and used to estimate indices of abundance. An analysis of data for primary species with an adequate sample size provides an estimate of abundance, occupancy and detection probability.

Maritimes Breeding Bird Atlas

The Maritime Breeding Bird Atlas (MBBA) provides information of the change in bird populations over time between the first (1986-1990) and the second (2006-2010) atlases. Atlas data

consists of an inventory of intensive bird surveys conducted in 10 x 10 km squares over a five year interval every twenty years. Data collection protocols and analysis are contingent on indicator species and metrix. Available data includes breeding evidence maps, relative abundance maps, geo-referenced point count data and rare/colonial species data, and habitat association analysis for most species detected on point counts. All analyses conducted to date using MBBA data are at the provincial or Maritimes-wide scale.